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A HISTORY OF THE CORROSION OF THE 36-INCH STEEL FORCE MAIN AT AKRON, OHIO.

BY G. GALE DIXON.*

General Remarks.

In the choice between the use of cast-iron and of steel-plate pipe for large water-supply mains, the element of least certainty is the depreciation to be expected in the steel pipe due to corrosion.

We are all familiar with certain classic cases of corrosion, the most thoroughly described of which was that at Rochester, N. Y.; but a great many cases must exist of which little or nothing is generally known — unfortunately, for the light which they might throw on a most perplexing subject.

We are told that the only salvation is absolutely to prevent the steel-plate from coming in contact with ground-water, yet we all know of steel pipe imperfectly coated which has lain in wet clay ground for years without trouble of any sort.

To date we have a background of corrosion of steel pipe under various sets of conditions approximately as follows:—

(1) *Ground-Water Corrosion.* I have heard of severe corrosion occurring on steel pipe at stream crossings in the Alleghenies due to mine drainage carried by the stream.

(2) *Corrosive Soil.* Notes have recently appeared in the technical journals commenting on the corrosion of cast-iron pipe in alkali soils of Western Canada.

(3) *Rapid Localized Corrosion with the Passage of Relatively High Electric Current.* The most striking case of this effect occurred at Pittsburgh, Penn., where Mr. E. E. Lanpher reports that stray electric current amounting to about 2 000 amperes following a new 36-in. steel pipe to the vicinity of a power house, cut through the $\frac{3}{8}$-in. plate within 90 days after putting the pipe in service. This condition was corrected by connecting

* Chief Engineer, Bureau of Water Works Improvement, Akron, Ohio.

the pipe with the negative bus of the adjacent power house, with slight total damage.

(4) *Corrosion in Salt Marsh.* At Atlantic City, N. J., cast-iron, steel-plate and wood-stave pipe were successively destroyed where the lines ran for three miles across salt marsh, the corrosion of the metal pipes and of the steel banding of the wood-stave pipe occurring about the upper portion of the circumference where air, water and vegetable matter met. Stray current was credited with no hand in the work, and the final measure in meeting the condition was the construction of a cast-iron line supported above ground by concrete piers. (*70 Engineering News, 1046.*)

(5) *"Auto-Electrolysis" or "Self-Corrosion" in Ordinary Grounds.* At Rochester, N. Y., severe corrosion attributed to the combination of soil conditions and imperfections in coating and steel, occurred over several stretches aggregating about six miles in length in the 26-mi. pipe lines conveying water to the city from Hemlock Lake. Corrosion was apparently confined to wet clayey soil. The corroded portions were scraped and repainted, and the deeply pitted sections were patched by strapping new plates on the outside.

Stray current was credited with no hand in this. (John F. Skinner, "Steel Plate Pipe Conduit II," published by City of Rochester, 1913.)

The case at Portland, Oregon, was quite similar to that at Rochester. Serious corrosion was discovered over a two mile stretch of the 24-mi. Bull Run pipe line before the electrification of railways crossing and paralleling it. The line varies from 33 in. to 42 in. in diameter, and the plate from $\frac{1}{4}$ to $\frac{3}{8}$ in. in thickness. The worst corrosion was observed in very wet clay ground, relatively drier clay showing less active corrosion, and none occurring in sandy ground. Pitting was most concentrated on the sides and top of the pipe.

The line was laid in 1893-4, serious corrosion was observed by 1905, electrification of one adjacent railway was achieved in 1905-6 and of the other in 1913.

In 1914 little weight was given the electric railways in corrosion effect, though steps were taken to prevent damage by them. (Report of U. S. Bureau of Standards, "Electrolysis conditions on Bull Run Pipe Line, Portland, Ore., 1914.")

At both Rochester and Portland the soils and ground-waters were regarded as of not peculiarly corrosive character.

The Akron Case.

The case which is our present subject falls in none of these specific classes:—

It is that of a 36-in. lock-bar steel force main 11 miles long at Akron, Ohio, which after five years service evidenced very severe corrosion in wet clay ground over a stretch less than a mile in length; mild stray current was

found flowing on the pipe and leaving it in the corroding area at a point three miles from the nearest trolley tracks, to follow a route of low resistance in the natural ground back to the equally distant power-house.

A case possibly closely parallel is commented on by Herman Rosentreter in the *American Water Works Journal* of 1917, in discussing a paper on Electrolysis by Prof. Ganz: —

"An electric railway running southwest from Paterson, N. J., is paralleled by a 42-in. main supplying Jersey City. A 42-in. and 48-in. main supplying Newark, N. J., intersects the railway and runs directly

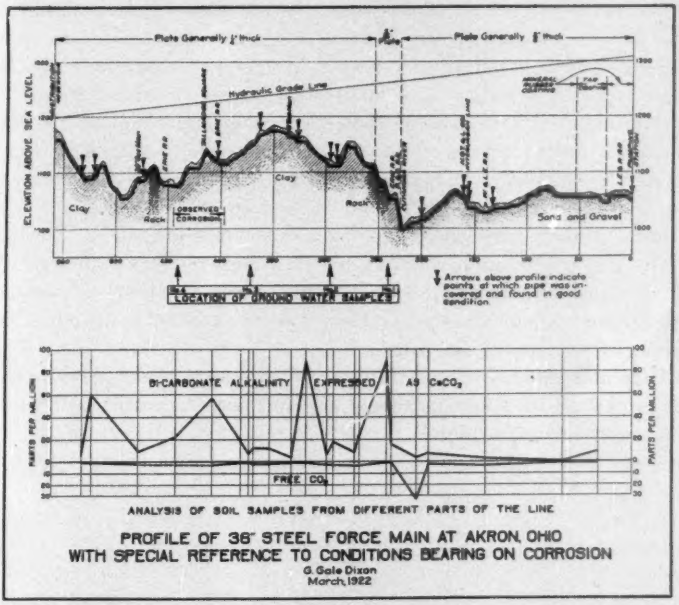


Plate Generally ½" thick
Plate Generally ⅝" thick
Hydraulic Grade Line
ELEVATION ABOVE SEA LEVEL
Clay
Rock
Clay
Rock
Sand and Gravel
LOCATION OF GROUND WATER SAMPLES
Arrows above profile indicate points at which pipe was uncovered and found in good condition.
BI-CARBONATE ALKALINITY EXPRESSED AS $CaCO_3$
FREE CO_2
PARTS PER MILLION
ANALYSIS OF SOIL SAMPLES FROM DIFFERENT PARTS OF THE LINE
PROFILE OF 36" STEEL FORCE MAIN AT AKRON, OHIO
WITH SPECIAL REFERENCE TO CONDITIONS BEARING ON CORROSION
G. Gale Dixon
March, 1922

PLATE II.

away from the station supplying current for the cars. A leak was reported in the Newark main in a swamp about 3½ miles from the railway crossing. Investigation showed that the main was carrying 20 amperes at the break and only 2 amperes several miles beyond, and tests made on the main when the cars were not running showed that there was a slight current in the reverse direction, thus showing that stray electric currents are found about eleven miles from the power station."

General Description of the Pipe Line.

This pipe line was constructed in 1913-1914 under the direction of F. A. Barbour and E. G. Bradbury, Consulting Engineers for the City of Akron; a most thorough-going supervision was maintained on all processes, from the records of which much of the following matter is drawn.

As indicated in plan on Plate I (following this paper) the line lies almost straight to the northeast from the city limits to the pumping station, crossing the Cuyahoga River at a point somewhat more than midway of its length.

It runs through open farming country for the most part, the portion south of the river-crossing following a country road except for a detour to avoid a high knoll, while the northerly portion is laid in private right-of-way through the fields.

It will be observed on the profile of Plate II that the terrain traversed by the line differs markedly both in topography and in geological characteristics on the opposite sides of the river: To the north of the river the line follows quite closely the water-shed line of a gently sloping surface, and is laid practically in its entirety in sand and gravel, with occasional admixture of small proportions of clay; while to the south of the river it climbs through the more steeply rolling clay ground classed on the geological maps as the northerly edge of the "coal measures," encountering a little shale rock and crossing numerous small drainage channels, the largest of which is in the corroding area just to the southwest of Tallmadge Center, and drains country extending a mile back of the pipe-line.

The pipe was manufactured by the East Jersey Pipe Co. at Paterson, N. J., of plates ranging generally in thickness from $\frac{1}{4}$ inch at the southerly end of the line to $\frac{3}{8}$ inch at the northerly end. In cases of heavy cover over the pipe, thicker plates were used.

The plates are of open-hearth steel, approximately the grade of "Flange Steel," rolled by the Carnegie Steel Co.; mill tests compared with specification requirements as follows: —

	Specified Limit	Range of Test Results
Carbon		0.12 to 0.20%
Phosphorus	0.05%	0.01 to 0.038
Sulphur	0.05	0.025 to 0.04
Silicon	0.05	
Manganese	0.50	0.30 to 0.50

Ingot tops were cropped to sound metal, the discard reported by the mill inspector on 17 per cent. of the ingots averaging 27.3 per cent. by weight, and ranging from 20 per cent. to 80 per cent.

Mill and shop inspection was performed by the Pittsburgh Testing Laboratory, in continuous consultation with Mr. Barbour.

The plates were "pickled" to remove mill-scale by soaking for one hour in 10 per cent. sulphuric acid solution, followed by dipping three times in soda ash solution and an equal number of times in constantly changing water.

The finished pipes were thoroughly cleaned before dipping.

The specifications provided for coating the pipes by dipping in hot "coal tar pitch varnish," but this material was used on only about a half-

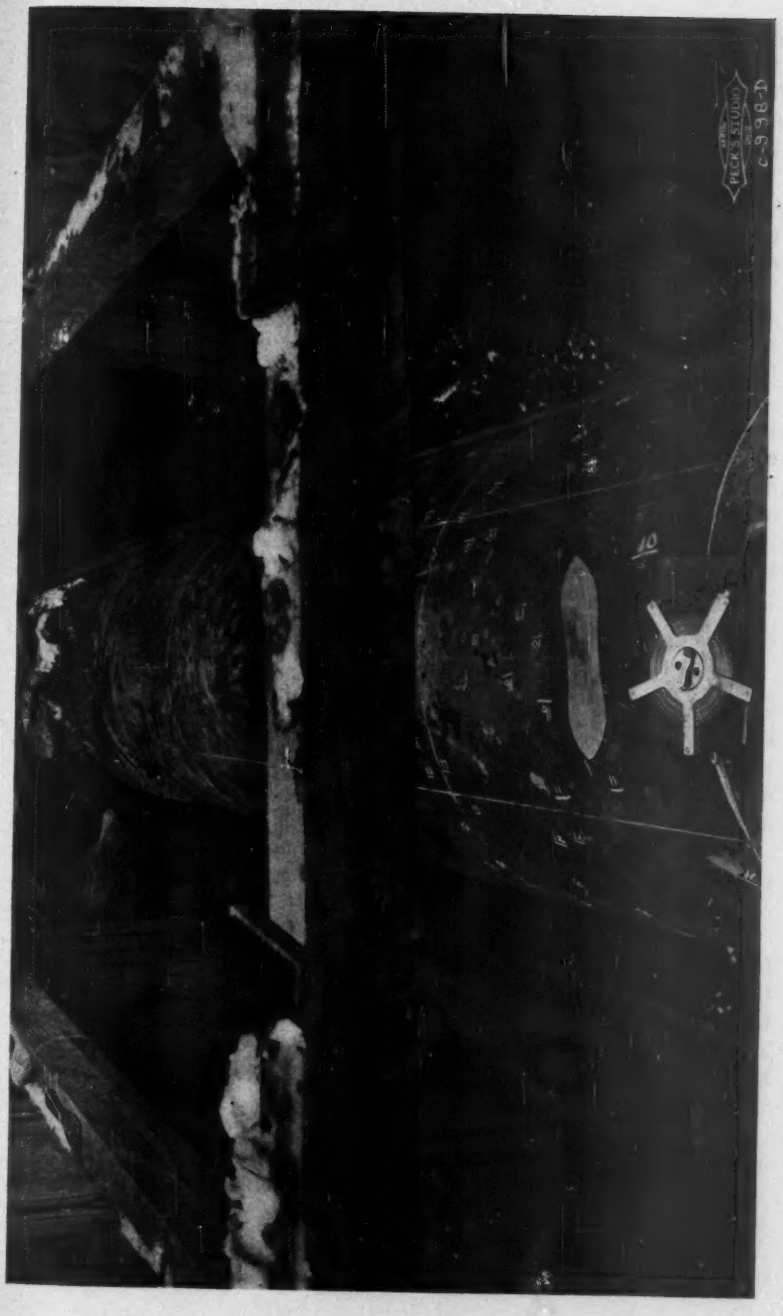


PLATE III. PHOTOGRAPH OF CORRODED STEEL PIPE AT STATION 440.

mile of the line owing to the difficulties encountered in so controlling the mixture and the temperature of bath and pipe that the resulting coating would neither flake at low temperature nor run at high. The remainder of the line was coated with "Pioneer Mineral Rubber," manufactured by the American Asphaltum and Rubber Co.

Delivery of the pipe on the ground was effected between November 21, 1912 and April 23, 1913. Pipe laying was started in May 1913 and completed in July 1914, so all of the pipes were exposed to the weather of practically a full winter season, while the tar-coated material between Stations 27 and 55 lay out through two winters.

A peculiarity noted in regard to the mineral rubber coating was the breaking down of the material on the exterior of the pipe where it had lain for long in contact with the sod, entailing considerable repair work.

In the spring and summer of 1914, inspection of the completed pipe showed considerable failure of the interior coating by coming loose, especially near the field joints; the line was thoroughly gone over, all loose coating removed, the steel cleaned, and two coats of commercial metal paint applied.

The line was put in service in August, 1915, since which date it has been in continuous service supplying filtered water to the city.

Corrosion Discovered.

In May, 1919, the pipe was uncovered at eight different points in wet clay ground south of the river-crossing, for the purpose of examining the condition of the exterior surface in connection with the preparation of specifications for a proposed paralleling line. In all cases the condition was found to be good; coating in some spots was brittle and in others thin or easily removed, but no pitting was observed nor rust under loose coating.

Several other inspection pits were dug later north of the river, exposing equally good conditions. The location of all these excavations are indicated on the profile of Plate II.

In November 1919, interior inspection of the pipe at a point about 1 000 ft. southwest of Tallmadge Square (Sta. 440) disclosed two holes eaten through the plate as the source of leakage which had been observed for some time on the surface, but which had been attributed to ground water. These holes were plugged from the inside and a sixty foot stretch of the line was then uncovered, showing a very severe condition of corrosion which is illustrated in the photograph in Plate III.

The chalk figures appearing on the pipe in Plate III register the measured depths of the larger pits in hundredths of an inch.

Three or four times as many pits were observed above the horizontal center line than below.

The corrosion phenomena inside and out conformed with what has been most excellently described at Rochester and Portland. Inside, the original

coating showed numerous blisters from ⅛ to 1½ inch in diameter, which when punctured and removed disclosed bright steel with a slight roughness in the center; in other places tubercles were found covering shallow "saucer shaped" pits. On the exterior, the "cup shaped" pits usually contained at the bottom a small quantity of material resembling white lead paste, though in some cases a pale brownish color was observed.

In several places long shallow pittings apparently followed where the coating had been scratched by a pick or shovel in back-filling, and in another case near the end of a pipe a similar condition had followed abrasion due to the cable sling with which the pipe was handled.

The excavation was held open for some time, and the conditions were observed by Mr. Frank Wilcox, Engineer for the T. A. Gillespie Co., Mr. W. R. Veazey, Professor of Chemistry at Case School of Applied Science, Cleveland, Mr. E. E. Lanpher, Engineer of Distribution of the Pittsburgh Water Department, and Mr. L. G. Tighe, Superintendent of Power for the local traction company.

A volt-meter test over the exposed pipe showed a considerable flow of current to be occurring on it.

To date a total of nearly 20 holes in the plate have manifested themselves by leakage appearing on the surface, all in the vicinity of Tallmadge Center (between the Erie Railroad at Station 400 and the brook at Station 445); these have all been plugged from the inside.

Comments by Professor Veazey.

The following extracts from a report on the matter by Prof. W. R. Veazey summarize his views:—

"The soil in which the Akron water main is laid, insofar as I have seen it, seems to consist of sand, clay, shale, ashes and various combinations of these. In general the soils are wet and have a tendency to hold water. Such soil conditions are very favorable to pipe corrosion either by galvanic action or by stray electric currents. Without going into detail, it is my opinion that a soil survey will be of little value except to confirm the statement I have just made that the general soil conditions are favorable to rapid corrosion of steel pipe."

* * *

"According to the geological map, you may expect to find glacial drift anywhere along the present pipe line except at Tallmadge, and for a distance of from one-half to one mile on either side of Tallmadge in the direction of the pipe line. At Tallmadge and vicinity you will likely find pyrite bearing shales and clays which are extremely favorable to corrosion of steel for the following reason: Pyrite is a sulphide of iron which is readily acted on by water and air to form the soluble salt ferrous sulphate (green vitriol) and also free sulphuric acid. The ground waters in the vicinity are nearly always impregnated heavily with the above salts and sulphuric acid. Since such ground waters are extremely favorable to the process of corrosion, any contact of the steel with such shales or clays or ground water coming from such shale or clay must be absolutely avoided."

* * *

"Steel, if kept dry, will not corrode. Although this condition probably cannot be absolutely maintained in a practical way, yet the more nearly it is approached, the longer will be the life of the pipe line. There are two ways of obtaining results in this direction, both of which should be applied: Efficient under drainage of the ditch in which the pipe is laid and a proper paint or protective coating for the steel."

* * *

"With reference to the kind of protective coating to be used on steel pipe: Insofar as my present information goes, the best protection is to paint the steel after it has been completely freed from mill scale, with red lead and oil, giving it two coats, and then after the pipe has been laid, an additional two coats of the same paint should be applied. I am of the opinion that the Bitumen coating which has been applied to your present 36-in. line is not beneficial in the long run because, although when new it may protect the steel from moisture, it has a tendency to become porous and spongy with age and then acts in the opposite way and retains moisture and thus actually stimulates corrosion. You will find evidence of this in spots where the Bitumen coating is blistered or raised up by the corrosion deposit underneath it."

* * *

"With reference to stray electric currents from power houses and power lines: Such currents should of course be eliminated by discovering their source and breaking the electrical connection, but this certainly is not the chief cause of corrosion on your steel line, even though it may be a contributing factor. Eliminate wet conditions along the line and this factor will drop out."

Electrical Conditions.

Mr. E. E. Lanpher, who has had a long experience in electrolysis and corrosion at Pittsburgh where much steel pipe is in use, was retained in an advisory capacity: owing to his many duties he was unable to follow the work actively in the field.

Referring again to the map of Plate I, it is to be observed that the city and interurban lines of the Northern Ohio Traction and Light Co., swing a rough arc to the northwest of the force main, the Akron-Kent-Ravenna line crossing it about a mile and a quarter beyond the river-crossing. The various substations are also shown, as well as gas mains.

It is to be noted that the location of observed corrosion is at a sort of focal point of all the obvious natural and artificial features of the locality — a high tension line passing right through the center of the affected area is not shown, as all thought of its influence was early discarded.

In December 1919 a milli-voltmeter survey of the pipe-line made with wires about 1 000 ft. long stretched between access-manholes indicated a current flow of about 20 amperes from Akron toward the corroding area at Tallmadge, and continuing on toward the point of crossing of the trolley line near Kent in about half that quantity; from the trolley crossing to the pumping station the current was much smaller in quantity and with quite rapid and uniform reversal of direction. The flow between Akron and the trolley crossing of course reversed at intervals, but there was evident a

definite flow toward the Kent substation. Following this survey, the traction company went over the rail-bonding of its interurban lines, which was in bad shape, and an appreciable improvement in conditions was noted.

At the suggestion of Mr. Lanpher, a bond between the pipe and the rails near the Kent substation was inserted for test purposes, but was not put in regular use as it made the condition at Tallmadge worse.

Soil and Ground-Water Analyses.

Soil samples taken at the level of the pipe line were gathered from 23 test pits scattered over the length of the line, and the results of tests for "Free CO_2" and "Bi-carbonate Alkalinity expressed as $CaCO_3$" are shown graphically in the lower part of the profile, Plate II. Marked difference between the conditions on opposite sides of the river is here again apparent.

Ground water samples were also analyzed with the following results:

Sample No. (See Plate II)	1	2	3	4
Location	Sta. 239	Sta. 295	Sta. 370	Sta. 440
Character of Soil	Yellow Clay	Yellow Clay	Clay	Fill
Character of Vegetation	Road	Grass	Wheat	Road
Chlorine	10.0 ppm	5.0 ppm	6.0 ppm	10.0 ppm
Bicarbonate Alkalinity	276.0 ppm	3.5 ppm	5.0 ppm	128.0 ppm
Free CO_2	34.0 ppm	7.0 ppm	20.0 ppm	28.3 ppm
Nitrates	0.2 ppm	0.24 ppm	6.0 ppm	

Sample No. 4 was from the excavation for inspection of the corroded pipe near Tallmadge.

Repair of Exposed Pipes.

The two corroded pipes which had been uncovered for examination were finally carefully cleaned, the deeper pits flushed up with metal by the oxy-acetylene flame, and the pipes were painted with "Hermastic Primer" followed by "Hermastic Enamel" applied hot. The trench was underdrained and backfilled with clean sand and gravel.

Mr. E. E. Brownell's Report.

In August, 1920, Mr. E. E. Brownell, a consulting engineer employed by the Akron City Council to advise in the framing of a new traction franchise, was requested by the Council to review the situation in regard to electrolysis; he made a volt-meter survey of the city lines and the force-main, and the following excerpts regarding the force main are taken from his report of December 24, 1920:—

"The electrolytic condition of the 36-in. steel force main is one of the most intricate that the writer has experienced in many recent years of experience. It is almost unbelievable how far distant the operation of the various substations influences the electrolytic condition of this valuable water artery."

* * *

"Everything is in favor of steel or wrought-iron force main construction, if the coating features are respected and due care and consideration be employed during such construction, so as not to permit the coating to become broken or abrased. This is the whole secret of steel force main protection. The electrolytic conditions should be corrected immediately upon the completion of the installation and all valves bonded over with heavy copper cables, so as to render impossible electrolytic action at an unintentional insulated pipe joint."

Report of Mr. E. E. Lanpher.

With all of the data as previously outlined at hand, and after several brief inspection trips on the ground, Mr. E. E. Lanpher, Superintendent of Distribution of the Pittsburgh Water Department, gave final advice under date of March 29, 1921, as follows:—

"No one of the soil analyses shows a dangerous content from a galvanic action standpoint. Practically the same statement is made in regard to the water analyses; for while it is true that the chlorine, nitrate and carbonic acid content would indicate a slight galvanic action, I am of the opinion that this action would not be serious where positive electric currents were absent. With such currents absent I would not hesitate to lay steel pipe under the conditions as shown by these analyses and with the expectation that a coating of concrete or extensive drainage operations would be a poor investment.

"There is no doubt in my mind that the soluble salts and the carbonic acid present in all the clay and in the coarser gravel soil will account for considerable electrolytic and accelerated galvanic deterioration where the soils are wet and in presence of positive electric current. Where the soil is dry these salts and acid do not appear to be present in sufficient quantity to account for great electrolytic damage under present positive current flows. I believe, however, that some deterioration will be found in the so-called dry soils, and it is certain that the positive current flows will increase as the power station loads are increased. In fact, it appears that in dry soils very little galvanic or electrolytic damage is in evidence at the present time:— not enough to warrant large expenditures for pipe coating.

"There is nothing in the soil and water analyses submitted to change my opinions under date of January 27th, 1921. I am still of the opinion that prompt action must be taken to eliminate all zones of positive electrical potential and that this action will render the steel pipe practically safe except possibly in the low ground near Tallmadge; and even at this point it would be advisable to defer coating operations providing electrolysis mitigation work could be started at once."

Investigations Directed by Crecelius and Phillips.

Owing to Mr. Lanpher's inability to spare the time to trace down and correct the complicated electrical conditions the services of Crecelius and Phillips, Consulting Electrical Engineers of Cleveland, were secured for this purpose early in March, 1921.

Mr. L. P. Crecelius is a member of the "American Committee on Electrolysis," representing the American Electric Railway Association,

and Mr. Victor B. Phillips served as his alternate on one of the sub-committees.

Mr. Phillips is covering the later features of the investigation in thorough manner in a paper which follows this, entitled "Mitigation of Electrolysis on Steel Force Main at Akron, Ohio," but to make the record here complete a very brief statement of results will be made.

Three series of tests were made on March 9, 10, 11; April 18, 19; and June 11, 1921. In all of these the engineering force of the Northern Ohio Traction and Light Co., under Mr. L. G. Tighe, Superintendent of Power, coöperated to the fullest extent, and at the second test Mr. E. R. Shepard of the U. S. Bureau of Standards also assisted with special instruments developed for the purpose by that organization.

Additional soil samples were also taken and submitted to the U. S. Department of Agriculture and to the Bureau of Standards for analysis.

The first two tests indicated mild stray current flowing on the pipe line toward Tallmadge from both ends, leaving the pipe in the corroding area, to follow some line of low resistance in the ground. The Northern Ohio Traction & Light Co. during the months of April and May, succeeded in putting its system in electrical balance with the force main by re-bonding its tracks in the vicinity of the Gorge, High Street and Brittain sub-stations, and installing an insulated negative feeder on North Hill. This balanced condition was demonstrated by the tests of June 11, and the following quotation from Crecelius and Phillips' final report of June 23, 1921, gives a full summary of their conclusions:

(1) "That electrical conditions on the system of the Northern Ohio Traction & Light Co. are at this time so balanced as to eliminate the presence of current in serious quantities on the steel force main.
(2) "That there exist no geological formations that may serve as a natural battery with resultant galvanic currents.
(3) "That there is no danger from soil corrosion.
(4) "That there exist local galvanic currents due to presence of scale and also possibly to differences in the composition of the metal; and that the mains should be inspected from time to time to determine the seriousness of such local galvanic currents.
(5) "That periodic tests to determine current flow on force mains should be made in the future and that permanent test stations for such measurement may be installed to advantage.
(6) "That conditions are such as to permit the use of steel pipe without unusual danger (especially inasmuch as cast-iron pipe has already been laid in the dangerous area near Tallmadge)."

Construction of Paralleling Line.

The investigations as outlined were of especial urgency and importance in connection with the determination of policy to be pursued in connection with the construction of a paralleling 48-in. line demanded by Akron's rapid growth.

Before the corrosion at Tallmadge had been discovered, the second line had been constructed of lock-bar steel pipe from the city to the southerly end of the corroded portion.

In 1920 the northerly four and a quarter miles from the river-crossing to the pumping station was also built of steel, as by that time a firm belief had been established that there was nothing to fear in that part of the line. During the same season start was made in laying about 0.9 mile of paralleling cast-iron pipe through the corrosion area.

Before the contract was advertised, in the spring of 1921, for the remaining 3.2 miles from Tallmadge Station to the river-crossing, practically final conclusions of the investigations herein outlined had been reached, and this portion was constructed of steel.

All of the steel pipe in the second line was coated with "Hermastic Pipe Dip."

Some Questions.

Would not a thorough-going compendium of steel pipe experience, gathered through the agency of one of the Water Works Associations, be well worth its trouble?

In the recent past, the excess cost, in the ground, of large cast-iron pipe over that of steel-plate pipe has ranged around 50 per cent., even in the East; but this handicap will probably be materially overcome in the near future and the expectancy of life of steel will have to be more closely estimated.

If such a digest were undertaken, special consideration should be given to uniform graphical representation of the surrounding conditions bearing on corrosion.

Another item worthy of a digest is the sudden rupture of large pipes, both cast-iron and steel; breakage of cast-iron pipes has been quite fully covered at Detroit, Cincinnati and New York, and occasionally we hear of similar occurrences in steel pipes. Freedom from such rupture is commonly credited as one of the strongest points in favor of steel, but we should have a history of the subject on record.

There are various questions in the design of steel pipe lines which are still somewhat open:—

(1) Location of justifiable use — in the country only, or also for primary feeders in the distribution system of the city?

(2) And in the country, does the saving in cost of acquiring private right-of-way justify the laying of pipe in a convenient highway, with its attendant later troubles in repair?

(3) What of water hammer? Very definite policies are laid down for cast-iron pipe on this point.

(4) For what condition should air valves be proportioned?

(5) The theoretical analysis of a pipe to withstand internal water pressure is simple, and safe depths of cover for given diameters of pipe and

thickness of plate have been worked out. But in various places we see steel pipe used at a minimum plate thickness of $\frac{1}{4}$ inch, selected purely on the basis of general judgment. Do the uncertainties justify the narrowing of limits of plate thickness down to conform somewhat with the various classes of cast-iron pipe?

(6) Should a steel pipe line be rigidly anchored, or should it be left free to "breathe"?

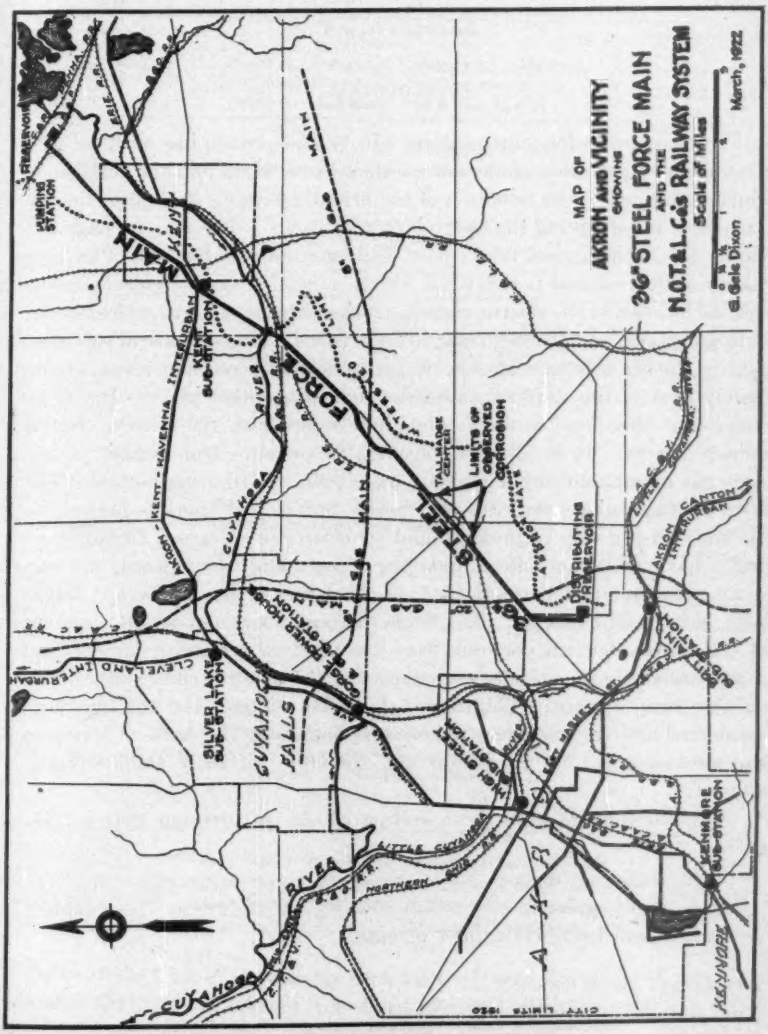


PLATE I.

INVESTIGATION OF ELECTROLYSIS ON STEEL FORCE MAIN AT AKRON, OHIO.

BY VICTOR B. PHILLIPS.*

[*Read March 17, 1922.*]

INTRODUCTION.

In his paper before this meeting, Mr. G. Gale Dixon has outlined in a general way the history of the Akron Steel Force Main and the conditions which finally led to the retention of the firm of Crecelius & Phillips for the purpose of investigating the electrolytic conditions. The map on page 169 shows the 36-inch steel force main leading from the Earlville Pumping Station to the reservoir in the city of Akron, a distance of about eleven miles, and the location of the electric railway tracks, substations, gas mains, steam railroad tracks, and the principal city water main connections to the force main. Rather serious corrosion of the main had been discovered immediately west of the town of Tallmadge and at no other place. It will be noted that this point is more than three miles from the nearest electric railway tracks. It is also at considerable distance from either of the large gas mains that might possibly have been contributing factors. The town of Tallmadge comprises only a few houses and there is nothing in the town in the way of underground structures or electrical circuits that might have had some effect upon the force main. In a word, the corrosion was found at perhaps the one point on the main where it might least have been expected. For these reasons it was not at all apparent at the outset that the corrosion was due to electric railway current, and it was necessary to carefully consider all of the possible causes other than railway stray current. The case is distinctly unique, and the questions considered and the procedure followed in diagnosing the cause of corrosion and providing for its correction are, therefore, of more than ordinary interest.

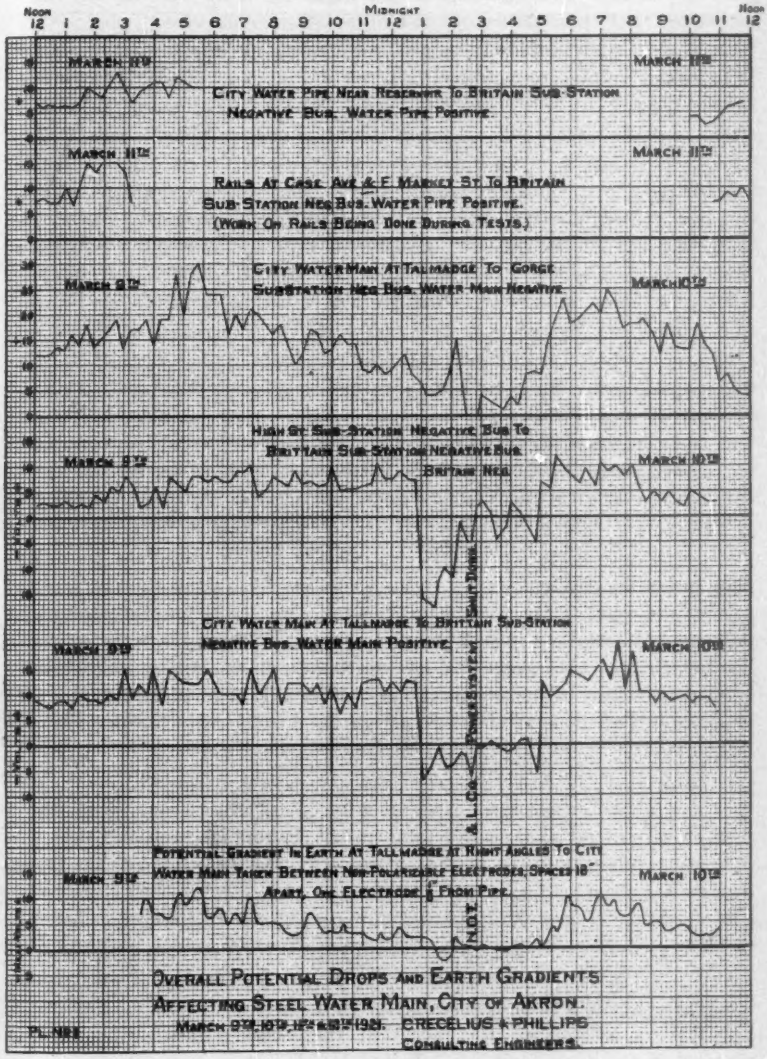
In studying the case, the following causes of corrosion were investigated:

(a) Railway Current
(b) Soil Corrosion
(c) Small Local Galvanic Currents.

*Of Crecelius & Phillips, Consulting Engineers, Cleveland, Ohio.

Railway Current.

Preliminary tests upon the force main showed that current was flowing away from Akron in the direction of Tallmadge to the extent of about 20


Noon 12 1 2 3 4 5 6 7 8 9 10 11 Midnight 12 1 2 3 4 5 6 7 8 9 10 11 Noon 12
March 11th
March 12th
City Water Pipe Near Reservoir to Britain Sub-Station Negative Bus. Water Pipe Positive.
March 11th
March 12th
Rails at Case Ave & E. Market St. to Britain Sub-Station Neg. Bus. Water Pipe Positive. (Work on Rails Being Done During Tests.)
March 9th
City Water Main at Tallmadge to Gorge Sub-Station Neg. Bus. Water Main Negative
March 10th
March 9th
High St. Sub-Station Negative Bus to Brittain Sub-Station Negative Bus.
Britain Neg.
March 10th
March 9th
City Water Main at Tallmadge to Brittain Sub-Station Negative Bus. Water Main Positive.
South Dam
A. L. Co. Power System
March 10th
March 9th
Potential Gradient in Earth at Tallmadge at Right Angles to City Water Main Taken Between Non-Polarizable Electrodes, Spaced 18" Apart, One Electrode 1/2 from Pipe.
N.O.K.
March 10th
Overall Potential Drops and Earth Gradients Affecting Steel Water Main, City of Akron.
March 9th, 10th, 12th & 13th 1921. Cregelius & Phillips Consulting Engineers.
Pl. No. 8

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INVESTIGATION OF ELECTROLYSIS ON STEEL FORCE MAIN AT AKRON, OHIO.

BY VICTOR B. PHILLIPS.*

[*Read March 14, 1922.*]

INTRODUCTION.

In his paper before this meeting, Mr. G. Gale Dixon has outlined in a general way the history of the Akron Steel Force Main and the conditions which finally led to the retention of the firm of Crecelius & Phillips for the purpose of investigating the electrolytic conditions. The map on page 169 shows the 36-inch steel force main leading from the Earlville Pumping Station to the reservoir in the city of Akron, a distance of about eleven miles, and the location of the electric railway tracks, substations, gas mains, steam railroad tracks, and the principal city water main connections to the force main. Rather serious corrosion of the main had been discovered immediately west of the town of Tallmadge and at no other place. It will be noted that this point is more than three miles from the nearest electric railway tracks. It is also at considerable distance from either of the large gas mains that might possibly have been contributing factors. The town of Tallmadge comprises only a few houses and there is nothing in the town in the way of underground structures or electrical circuits that might have had some effect upon the force main. In a word, the corrosion was found at perhaps the one point on the main where it might least have been expected. For these reasons it was not at all apparent at the outset that the corrosion was due to electric railway current, and it was necessary to carefully consider all of the possible causes other than railway stray current. The case is distinctly unique, and the questions considered and the procedure followed in diagnosing the cause of corrosion and providing for its correction are, therefore, of more than ordinary interest.

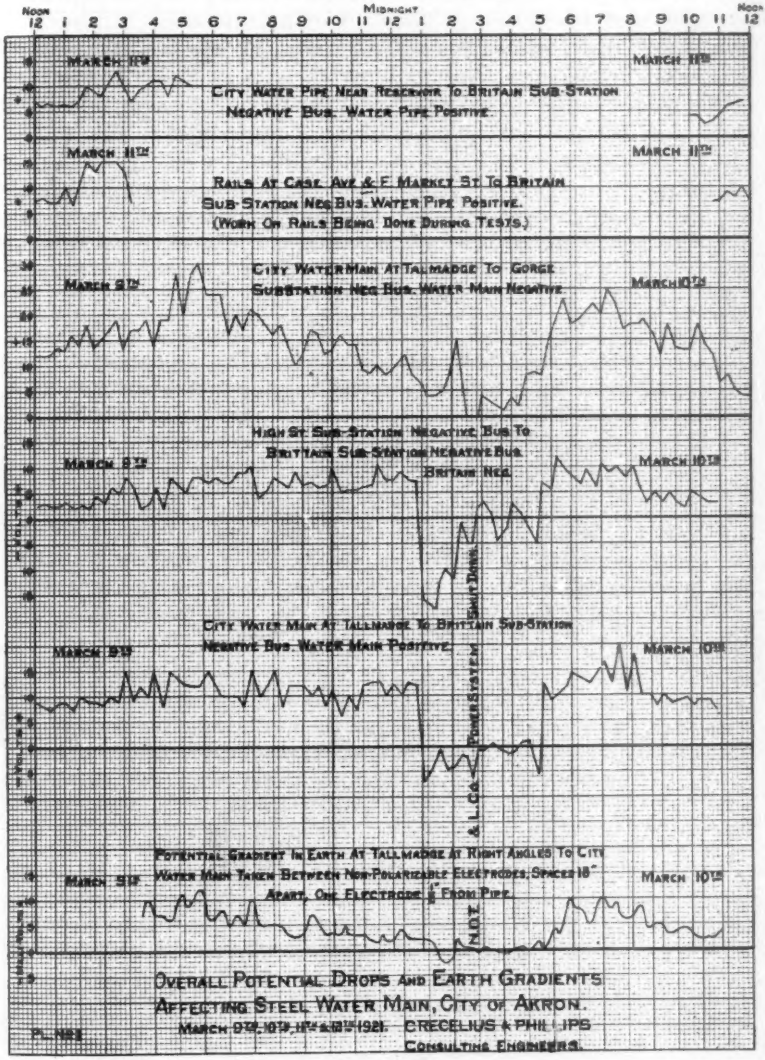
In studying the case, the following causes of corrosion were investigated:

(a) Railway Current
(b) Soil Corrosion
(c) Small Local Galvanic Currents.

* Of Crecelius & Phillips, Consulting Engineers, Cleveland, Ohio.

Railway Current.

Preliminary tests upon the force main showed that current was flowing away from Akron in the direction of Tallmadge to the extent of about 20


Noon
Midnight
Noon
March 11th
City Water Pipe Near Reservoir To Britain Sub-Station Negative Bus. Water Pipe Positive.
March 11th
March 11th
Rails At Case Ave & E. Market St To Britain Sub-Station Neg. Bus. Water Pipe Positive. (Work On Rails Being Done During Tests.)
March 11th
March 9th
City Water Main At Tallmadge To Gorge Substation Neg. Bus. Water Main Negative
March 10th
March 9th
High St. Sub-Station Negative Bus To Brittain Sub-Station Negative Bus.
Britain Neg.
March 10th
Short Drop.
March 9th
City Water Main At Tallmadge To Brittain Sub-Station Negative Bus. Water Main Positive.
March 10th
Power System
March 9th
Potential Gradient In Earth At Tallmadge At Right Angles To City Water Main Taken Between Non-Polarizable Electrodes, Spaced 18" Apart, One Electrode 6' From Pipe.
March 10th
N.O.T.
Overall Potential Drops And Earth Gradients Affecting Steel Water Main, City of Akron.
March 9th, 10th, 11th & 12th 1921. Crecelius & Phillips Consulting Engineers.
PL. 183

amperes at the time of the railway peak load. It was also found that there was some slight flow of current from Kent toward Tallmadge, although this current frequently reversed direction. Potential readings were taken be-

tween the force main and all metallic structures crossing it, viz: two gas mains and several railroad crossings. These voltage drops were found to be small, of the order of one volt or less, and apparently independent of the railway load and the magnitude of current on the main: It was, therefore, concluded that these structures had no bearing on the case.

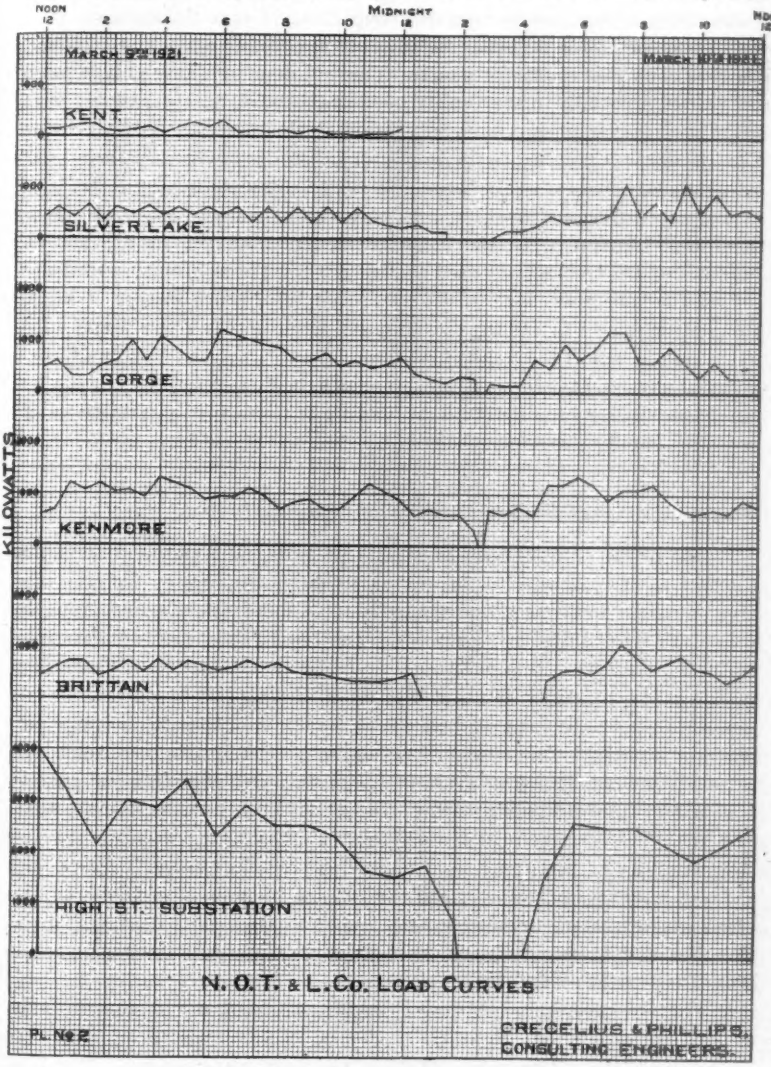
In order to determine the potentials causing the flow of current on the force main, voltage measurements were taken for 24 hours between the several railway substation negative busses and the force main at Tallmadge and at the Akron end. By means of these voltage readings it became possible to locate the point of minimum negative potential and thus to establish the path of the current. These readings are presented graphically on the accompanying curve sheet. They show that the negative bus at the Gorge Substation was the most negative point in the area under consideration. This fact served to indicate that the current which was apparently leaving the force main near Tallmadge was returning to the Gorge Substation. This fact, however, in itself could not be considered as conclusive evidence, inasmuch as it appeared unlikely that there was sufficient voltage difference to cause this current to flow directly across country for a distance of more than three miles.

In order to get a direct indication of the flow of current from the main into the earth in the locality of the corrosion, a 24-hour record was taken of the millivolt drop between two non-polarizable electrodes buried in the ground about eighteen inches apart and at right angles to the axis of the main, with one of the electrodes very close to but not touching the main. This potential gradient record is shown at the bottom of the curve sheet referred to above. It will be noted that the characteristic peaks and valleys of the curve, showing the voltage drop between the water main at Tallmadge and the Gorge Substation negative bus, are quite regularly co-incident, the only exception being between 1.00 A. M. and 2.00 A. M., when the High Street Substation negative bus became temporarily the most negative point on the system. At this time the flow of current in the earth near the force main reversed, as might reasonably have been expected. This information showed quite conclusively that there was a flow of current off of the force main in the Tallmadge area and that this flow was a function of the potential drop from the force main to the Gorge Substation negative bus.

A study of the geology and topography of the country between Tallmadge and the Gorge Substation disclosed the fact that there was an almost continuous low resistance path, due to creek beds and wet ground. The current was simply following this path.

Having established the fact that there was a measurable flow of current off the force main near Tallmadge directly across country to the Gorge Substation, it was then necessary to determine the reason for the current taking this long, roundabout and comparatively high-resistance path. At least one contributing cause was found to have been in the

rather long stretch of poorly bonded track between the High Street Substation and the Gorge Substation. Thus, a certain part of the power originating in the Gorge Substation positive feeders had to find its way back



to the Gorge Substation negative bus by another path than the high-resistance rail circuit. This increment of current then followed the tracks of the railway system into the High Street Substation and thence through a bonded connection into the city water system and into the steel force

main. It should be pointed out that the route followed by the railway, as well as the City of Akron, is all on high well-drained and consequently dry ground, so that there were no low-resistance ground paths by which this current might have taken a shorter route to the Gorge Substation.

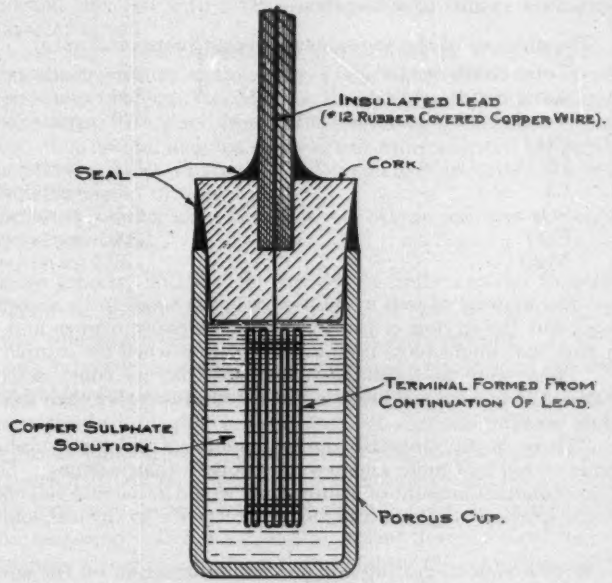
With the above information, it became a simple matter to eliminate the flow of current on the force main. This was done by thoroughly bonding the tracks, especially in the locality mentioned above, and by running out a negative feeder from the Gorge Substation, in the direction of High Street. This feeder was not tied to the tracks for a distance of three thousand feet, although the connection between the Gorge negative bus and the track at the substation was retained. In this way a part of the return circuit drop was transferred to the negative feeders with the result that the potential of the tracks was raised considerably. These *mitigative* measures served two purposes, viz: to provide a metallic return circuit of higher conductivity, and to reduce the potential drop between the force main at Tallmadge and the Gorge Substation. In this way an electrically balanced condition was obtained, and although the flow of railway current has not been entirely eliminated, it has been cut down to a negligible value, with continually reversing polarity.

Testing Equipment and Procedure.

Due to the unusual conditions that prevailed, it was found necessary to exercise extreme care in the testing methods employed. For the purpose of taking millivolt drops along the force main, special contactor rods were made up. These rods were of steel and had a twist drill welded to one end. The rods were heavily insulated with shellaced tape the entire length up to within one-eighth of an inch of the drill point. The purpose of this insulation was to prevent contact with the earth and thus to eliminate any galvanic potentials that might be set up as a result. The force main was reached by first driving down heavy bars and then inserting the contact rods in the holes made in this way. It was found necessary to use a millivolt meter of extremely high resistance in order to get accurate current determinations. Inasmuch as the potential readings along 15 feet of the main were but a fraction of a millivolt, due to the size of the main and the small magnitude of the current, it is apparent that these readings had to be taken with great care, since the slightest galvanic potentials would have completely vitiated the results.

The non-polarizable electrodes used in this work are of some interest. It was necessary that these electrodes be of low resistance. This was obtained by the construction shown in the accompanying cut. It will be noted that this type of non-polarizable electrode is very simple to make up. The copper terminal is formed from the lead wire by removing the insulation and doubling the wire back a number of times in order to get a large contact surface. In this way a welded or soldered joint is eliminated, the

latter type of joint being particularly undesirable because of the galvanic or thermocouple effects. The lead wire is brought out through a cork stopper, the junction being made watertight. The container, in which is placed a saturate solution of copper sulphate, is nothing more than an ordinary porous cup such as that frequently used in the laboratory.



NON-POLARIZABLE ELECTRODE.

Mr. Burton McCullom of the United States Bureau of Standards has recently developed a new instrument for measuring directly the flow of current in earth and also the *resistivity* of earth. After preliminary tests had been conducted on the Akron force main, as previously indicated, we requested the use of this instrument of the Bureau of Standards, and Mr. E. R. Shepard of the Bureau went to Akron and checked our observations by means of the new current measuring instrument. In connection with this instrument a very high-resistance millivolt meter (2 500 ohms) is used. This millivolt meter was used to check the current observations on the force main.

The recording millivolt meter used with the non-polarizable electrodes was of comparatively low resistance, so that the millivolt readings are not accurate, at least for the determination of actual current. They do, however, serve the purpose of showing the variations, which was all that was desired.

Soil Corrosion.

With a view to determining the possible existence of soil conditions that would corrode the steel pipe, a number of soil samples were taken in the affected area and sent to the Bureau of Soils of the United States Department of Agriculture. It may be of interest to quote from a letter received from Mr. Milton Whitney, Chief of the Bureau of Soils, in which are reported the results of soil analyses.

The analysis of the water soluble constituents follow:

Total Solids at 110°	670 parts per million
Total Solids ignited	560 parts per million
Total Solids by electric bridge	570 parts per million
CO_2	None
HCO_3	175 parts per million
CI	3.5 parts per million
SO_3	208 parts per million
CaO	200 parts per million
MgO	39.5 parts per million

"The amount of iron in solution was too small to be accurately determined, but the drying of the soil would probably oxidize and precipitate any iron that might have been in the solution when the sample was taken.

"There were no sulphides in the soil that we could detect, nor any indication of an acid condition in the soil solution other than that caused by carbon dioxide.

"There is an unusually large amount of calcium sulphate in this sample of soil and more magnesium sulphate than normal. The presence of this abnormal amount of soluble salts would accelerate soil corrosion and also electrolysis by giving a higher conductivity to the soil solution."

With a view to getting still further information on the subject of soil corrosion, Mr. Whitney's letter was quoted in a letter addressed to the Bureau of Standards, in reply to which the following was received:

"I do not know that we can add anything to Mr. Whitney's comments relative to the corrosive action of this soil. Until a large number of corrosion tests have been made on soils of different compositions we could only guess as to the effects of the chemicals contained in the Akron soil. So far as our knowledge goes, they do not appear to be of a particularly corrosive nature. More than a year ago we proposed to the Research Sub-Committee a program along this line, but nothing has been done up to date as you know. It would require tests, in some cases, extending over a period of years and the Bureau will not be able to undertake them until more funds are available.

"We believe that a resistivity measurement would throw more light on the questions of soil corrosion and electrolysis than will the chemical analysis. Not only is a high conductivity conducive to electrolysis, but it undoubtedly has an important influence on galvanic corrosion as well.

"We have found earths to vary widely in resistivity. Humus from New Orleans has a very low resistivity in the order of 800 ohms for one centimeter cube, while earth in this vicinity will vary from 5 000 to 15 000 ohms per centimeter cube. Ordinary clay soil will run from 1 000 to 4 000."

Soil samples were also sent to the Bureau of Standards for determination of resistivity. Mr. E. R. Shepard of the Bureau of Standards reported on these samples as follows:

"We have made electrical conductivity measurements on it with the following results: After removing stones and coarse matter the sample was saturated with distilled water. In this condition it had a resistivity of 3 890 ohms for 1 cm^3. This soil appears to be, so far as resistivity is concerned, a normal clay soil with a resistance somewhat above the average for that character of soil.

Black loam from New Orleans had a resistance of about 600 ohms, and that from the downtown section of St. Louis about 900 ohms. Several samples of soil collected from Des Moines, Iowa, had an average resistance of about 1 800 ohms. Clay soil from Pittsburgh had a resistance of about 2 500 to 3 000 ohms. Philadelphia clay soil will run somewhat higher than these values, and the red earth around the Bureau of Standards has a resistance of 15 000 ohms and upward.

"As compared to other soils, therefore, the Akron soil does not appear to be in any way unusual."

The above reports, both by the Bureau of Soils and the Bureau of Standards, showed, insofar as the matter was subject to determination, that there was comparatively little likelihood of soil corrosion. It should be pointed out, however, as stated in Mr. Shepard's letter, that the entire subject of soil corrosion is but imperfectly understood. It is not possible at the present time to adequately interpret soil analyses. There is also some difference of opinion as to methods of taking samples and making resistivity determinations, and even were accurate determinations possible, there is still a lack of understanding of the relation between resistivity and local galvanic corrosion. In a word, at the present time the most that can be done is to draw a very rough comparison between the conditions as they exist in a particular locality with the average of conditions determined elsewhere. Any conclusions so drawn here are at the present time very much open to question. There is at present no way of determining by an examination of the corroded metal whether or not the corrosion has been caused by stray currents, by soil ingredients, or by local galvanic currents. None of these statements, however, should be taken to mean that soil analyses and resistivity determinations are of no value. On the contrary, they are perhaps particularly necessary where the use of steel pipe is contemplated, for they will at least serve to show whether or not conditions are distinctly unusual and dangerous.

Local Galvanic Currents.

Local galvanic potentials are extremely difficult of determination. They may be due to one or more of a variety of conditions, such as: lack of homogeneity in the pipe metal(e.g., there may be spots in which the carbon content of the steel is considerably higher than it is in the surrounding steel) scale; the presence of particles of coke such as occur in cinders; structures

of cast-iron or other metal in the vicinity of the affected structure; close proximity to a coal measure. These galvanic potentials will, of course, vary through wide limits, and there is no apparatus by means of which they may be properly measured.

In the Akron case it was found that there was an appreciable galvanic potential between the pipe and oxide scale, the steel being positive to the scale. Millivolt readings taken between different parts of the pipe or between clean pipe and scale, or between ground and pipe, were found to be in some cases even greater than the readings across the two non-polarizable electrodes used in the earth current observations and those obtained along the main by which the current flow in the main was determined. From this it becomes evident that in all the tests involving small potential readings, it is absolutely necessary to guard against the effect of these local galvanic potentials upon the readings desired.

It will frequently happen that when back-filling after a pipe has been laid, cinders or other foreign matter from the surface of the ground will be thrown into the trench in contact with the pipe. The effect of this may easily be more serious than a heavy stray current. Many cases are known where a heavy cast-iron pipe has been completely destroyed in a few months by the action of cinders.

As in the case of soil corrosion, it is difficult to generalize on the subject of local galvanic action. The most that can be done is to make a careful search for the presence of foreign materials or earth ingredients or adjacent structures that may produce galvanic currents.

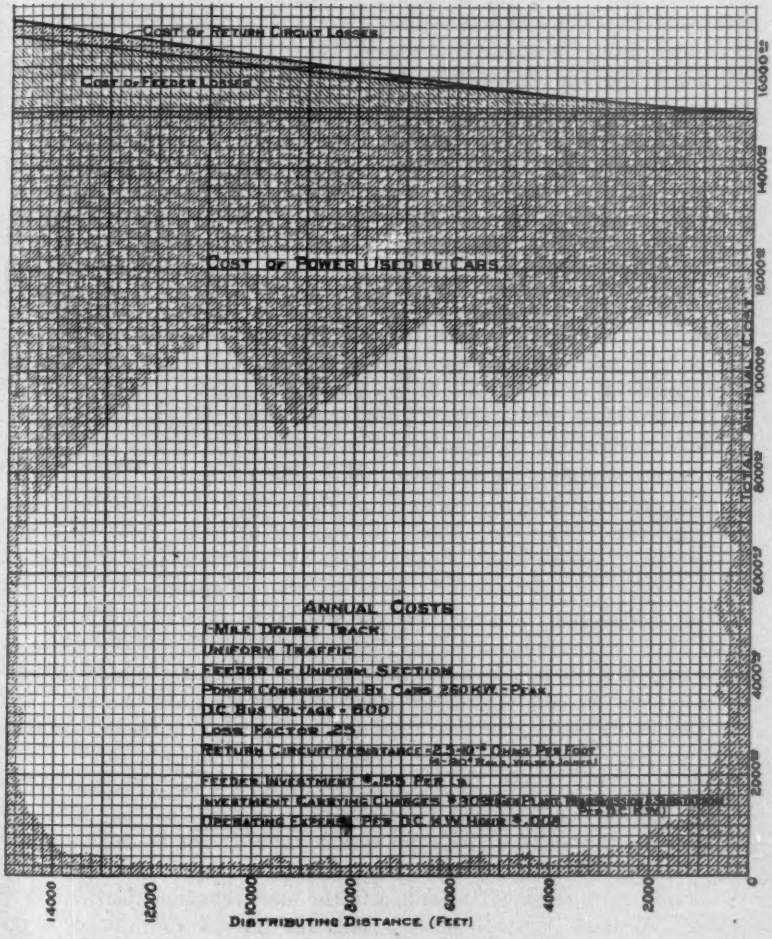
It may be noted at this point that the heaviest and most carefully applied coating is, under some circumstances, even worse than nothing so far as electrolytic corrosion is concerned. If there be a potential difference due either to railway stray current or local galvanic current there is a tendency for this current to seek the weak points in the coating and to concentrate. The result, therefore, may be a much more rapid corrosion than would take place if the current were more uniformly distributed over the surface of the structure.

Where there exists any doubt as to the possibility either of soil corrosion or of local galvanic action and the value of the pipe or other structure warrants the expense of excavation, regular inspection will prove the only satisfactory safeguard. This is particularly true of steel mains, inasmuch as they are much more subject to corrosion than cast-iron mains.

In the Akron case is it believed that the force main is reasonably free from both soil corrosion and local galvanic corrosion. Yet, here is a case where a very large investment, as well as the continuity of the water supply of the city of Akron, is involved. It would, therefore, be highly improper to assume that the question of soil and local galvanic corrosion has been settled once and for all. On the contrary, it should prove cheap insurance to make excavations from time to time at different points along the force main and observe carefully its condition.

Present Status of Electrolysis Question.

It is perhaps not amiss in a paper of this kind to say something of recent developments bearing upon the subject of electrolysis, caused by electric railway stray currents. This question has been very actively



studied for a number of years by all of the national public utility associations whose interests are affected. The American Water Works Association is one of these. The studies have been carried on by the American Committee on Electrolysis, in which these several interests are represented. The members of this Association are probably thoroughly familiar with the recent Report of the American Committee on Electrolysis. This report

represents the unanimous opinion of the representatives of all the different interests involved. It is undoubtedly the best text that can be found on this very live subject.

A matter of concern to the water companies and other pipe owning and cable owning interests is the study and development of railway distribution, and more particularly the automatic substation. Were it economically possible to install on a railway system a very large number of substations so that distributing distances would be cut down to, let us say for example, one mile or less, the track voltage drops that result in stray currents would be practically eliminated. The last two or three years have witnessed the advent of the automatic substation on a large scale. The principal justification of the automatic substation, or automatic substation combined with remote control, is to be found in decreased distributing distances, with the consequent saving in the cost of distribution and, what is also important, the reduction of stray currents.

At the present time it is impossible to generalize as to how far the matter of decreased distributing distances may be carried. The reason for this is that automatic control has not yet been standardized and the efficiency of the automatic substation varies through wide limits for different methods of operation. It has not been possible to determine just how some of these problems may best be worked out. Consequently, without more precise data on these points, it is difficult to make a satisfactory analysis showing how far this development may be carried.

The main question involved may be illustrated by means of the accompanying chart. This chart shows the component parts of the total cost of supplying a given amount of power to electric cars for a range of distributing distances. It will be noted that as distributing distances increase, the cost of distribution becomes a larger and larger part of the total cost of power. Consequently it follows that on interurban lines where distances are great, the reduction of distributing distance is a matter of more importance than in the case of city systems where distances are smaller. The automatic substation, therefore, finds its particular field at the present time on interurban railway systems or on long electrified steam roads.

It is perfectly safe to predict that the future will see a marked reduction in distributing distances on interurban lines as well as some reduction on city lines, although in the latter case it will of course be smaller. The electrolysis problem is therefore being solved to some extent by those developments in engineering leading to the more economic distribution of power. As these developments continue and the electric railways of the country profit by them, it is quite likely that the whole difficulty of electrolytic corrosion from stray currents will cease to exist.

Discussion. (Joint.)

Dixon and Phillips Papers.

The President. We have listened to two very interesting and valuable papers and I hope that the discussion will be up to the same standard and that we shall justify the courtesy of Mr. Dixon and Mr. Phillips in coming from Ohio and talking to us this afternoon.

On my right I see Major Leisen, ex-President of the American Water Works Association, and I think he might open the discussion. We are glad to have him here.

Major Theodore A. Leisen.* Mr. President, I came here for the purpose of listening to these papers, particularly the first one, — on corrosion,— and was very much interested in it.

I am hardly prepared to say anything that would add materially to what has been given here already. I laid some large steel pipe a number of years ago in Wilmington, Delaware, the first line of lock-bar pipe laid in this country,— and that pipe has suffered to quite an extent, principally from electrolysis. From the best knowledge that I have, based on a report received over a year ago, the general condition of that pipe was just as good as the day it was laid with the exception of those particular points where electrolysis had affected it. But this was not a condition that was peculiar to the steel pipe alone, as the cast-iron pipe in the same localities suffered practically to the same extent.

We are now laying steel pipe in Detroit, (a condition which we have been forced to by the excessively high cost of cast-iron) principally 42 and 48-inch sizes, but it is too early to say anything about results. The first pipe has only been in a little over a year, and of course it is too early to look for any change in condition.

The question of steel pipe seems really to narrow down to two factors, the coating, which is one of the most important things, and the character of the soil. First of all, the quality of the coating and the ability to get absolute adherence to the steel pipe, and proper protection of that coating in the field work. With all the safeguards that you can throw around the men who are handling the pipe, and all the instructions and orders that you can issue, it seems almost impossible to get the pipe from the cars to the ground, and then into the ditch, without materially damaging the original coating. The first trouble frequently is from slippage of the pipe on the skids of the cars. If the train in which it is hauled bumps around a good deal you will find that considerable of the bottom part of the coating is rubbed off at those points where it rests on the skids. Then too the chains and ropes used in lowering it are another important feature in causing abrasion. Too much stress cannot be laid on the fact that those abrased sections of the coating should be supplemented by extremely careful field painting. There is no question but what steel pipe is getting to be, and will become more and more, a factor in water works mains,

* Engineer, Board of Water Commissioners, Detroit, Michigan.

particularly on large lines and long lines, and it will be up to this and similar Associations and the members of the Associations, to study that question with a view to getting the very best results both in the coating and the handling for the protection of such lines as are laid from this time on. The second factor — character of soil — is of necessity a local one. If the soil is neutral no trouble should result, but acid soils should be thoroughly investigated before laying steel pipe.

I have been asked to present a paper on Steel Pipe before the coming convention of the American Water Works Association, and am rather in a quandary, with the short time between now and the date of the convention — May 15 — whether I am going to be able to get sufficient data together to present a paper that will really be of any value. If this paper could be postponed for another year it might be very interesting to try and obtain as complete records as possible of all steel pipe laid in the country, with reports on the condition of that pipe after years of service, and combine that into a fairly comprehensive report.

PRESIDENT BARBOUR. Many interesting questions concerning steel pipes are suggested by the papers of this afternoon.

In the first place, as stated by Mr. Dixon, it was originally planned to coat the Akron line with tar — the specifications requiring a straight run coal tar pitch and heavy coal tar oil to be used — the final results to be a coating tough and tenacious when cold and not soft enough to flow under summer heat. On about one-half mile of pipe, tar as specified was used, but, owing to the difficulty encountered in obtaining a coating that was not either too soft or too brittle and because of the inability of the manufacturer to get acceptable results and meet the required deliveries, the use of tar was given up and on the remainder of the line asphalt was used. As just stated, this change was made to facilitate delivery and should not be interpreted as indicating that the engineer of the work considered asphalt superior to tar.

The difficulty in the use of tar was in great part due to a wide range in the temperature to which the pipes were heated before dipping and to variation of temperatures in different parts of the same pipe. Asphalt will stand a wider range of temperature without apparent ill-effect than tar, and is thus favored by the steel pipe manufacturers who have no accurate control of the pre-heating.

Mr. Dixon has referred to the rapid deterioration of the asphalt coating and the necessity of extensive repair work before the line was put into service. This condition is chargeable in great part to the delay in laying the pipe owing to trouble between the primary contractor and the sub-contractor who did the excavation. The result of this disagreement was that the greater part of the pipes were exposed for many months to the weather — a most serious test for any coating — and, in my judgment, it does not follow that because the asphalt on the Akron line peeled off in sheets that this material should be generally condemned. On the other

hand, it is true that similar peeling of asphalt coatings have occurred in other new pipe lines, and it would be to the interest of the profession if more information as to these happenings were made public.

Mr. Dixon has also referred to the fact that the plates for the Akron line were pickled to remove mill scale. This was done by immersion in 10 per cent. acid at 100° F. for an hour, neutralizing in a soda bath and finally washing. The plates thus treated were silver bright when emerging from the final washing; and if there is any value in the removal of mill scale as a preventive of "self corrosion," the treatment of the Akron line went as far as is practicably possible in this direction.

Whether pickling had anything to do with the subsequent peeling of the coating may be debatable. After pickling a plate develops a smear of rust within a few minutes and, as fabrication and dipping of the pipes does not always keep step with the pickling, it may be that this accelerated rusting has a tendency to reduce the adhesion of the coating. Whether pickling to remove mill scale is worth while may be open to question.

It is to be clearly noted, however, that the corrosion of the Akron line—described in papers of Messrs. Dixon and Phillips — is not attributed to failure of the coating, or to soil conditions, or to local galvanic currents resulting from mill scale, or other causes of potential differences in the pipe. The rapid corrosion in less than one mile of the eleven miles of pipe line is charged to the effect of stray electric railway currents — the unusual condition being the great distance between the pipe line and the nearest electric railway tracks. The mitigative measures adopted involved the establishing of a more nearly balanced electric condition in the railway system so as to reduce the potential drop between the pipe line and the point in the railway system to which the current had been returning. It of course remains to be seen to just what degree these measures will eliminate further corrosion. The experience described should not be interpreted as an argument against the use of steel pipe.

Mr. Allen Hazen.* There is no doubt about the utility of steel pipes in large sizes in water works service. One of the most fundamental points of difference between steel and cast-iron is that steel is ductile while cast-iron is brittle. Because of its ductibility, the steel pipe will stand, without appreciable damage, pressure from soil and unequal loading that would destroy cast-iron pipe. In many places the added safety against rupture secured by the use of steel is a controlling reason for selecting it. The danger of breakage with cast-iron increases rapidly with the diameter. Steel pipe in large sizes is much safer.

Both cast-iron and steel corrode. Papers like the one that we have just listened to will help us in understanding this corrosion. We need to learn more about these matters, and we must find means to reduce corrosion and to prevent the excessive corrosion that sometimes occurs. In actual experience the excessive corrosions in actual lines of pipe through years

* Consulting Engineer, New York.

of service have amounted to only a small annual percentage of depreciation on the whole amount of such pipe in service.

I am sure that a careful examination of the oldest steel pipe lines in water works service would indicate a percentage of depreciation much lower than anyone would have thought probable when those lines were laid.

One of the causes of corrosion of steel pipe is the soil. That is, the soil in places contains some substance that accelerates corrosion of the outside of the pipe. A wet soil, and especially a soil that contains ground water with high mineral contents, makes corrosion more easy and rapid. In general a porous soil is believed to be a contributing factor, but some impervious soils are corrosive. Some times the pipe is laid and the first knowledge of the corrosive properties of the soil is obtained when corrosion of the pipe becomes apparent, but some conditions may be recognized in advance and guarded against. For instance, pipes commonly corrode on the outside where they cross salt marshes near tide water.

Corrosion of pipe by the soil may be prevented by surrounding the pipe with concrete. That adds to the cost, but so far as we know, it is a sure cure for soil corrosion, and if the trench is dug carefully for back fill with concrete it is possible to surround it with concrete at an expense that is not excessive.

Some steel pipe was so laid during the past year in the streets of a city in the middle west. It was surrounded by concrete at all places except where the natural soil was impervious clay, which was believed to be almost equal to concrete for protection. Steel pipe protected in that way may have a long useful life. It is certainly free from the danger of interruption of service by rupture — a danger which is always present with the largest sizes of cast-iron pipe.

When stray electric currents flow through steel pipes it is more often the cast-iron pipe and the services connected with it that suffer than the steel pipe itself. This is because the current most frequently leaves the steel through these attached lines. The author has described an unusual condition where the stray current left the steel pipe to go directly to the soil with attendant damage to the pipe.

MR. STEPHEN H. TAYLOR.* Mr. President, a 48-inch steel pipe, 8 miles long, was laid in 1897 and 1898, in connection with the New Bedford Water Works, being put in service in 1899. The pipe was $^5/_{16}$ inch thick and coated with asphalt inside and out. It was lap-joint riveted pipe. It has been inspected internally several times since it was put in and found in as good condition as might be expected. There have been some tubercles and some blisters. If the blisters are broken a little corrosion is found under them.

In laying the pipe it was very carefully inspected, and wherever the coating was knocked off in transit or in handling it was very carefully put back. We had occasion last year to make an opening in that pipe for

* Superintendent of Water Works, New Bedford, Mass.

connecting with a 36-inch line. This is the first, and perhaps the best test we have had of its actual condition.

The outside of the pipe was in almost perfect condition when we uncovered it. It was in a gravelly soil — very wet but gravelly, and by just brushing it off and putting on a coat of black paint it looked almost like new pipe. The deepest pittings shown on the photograph I believe were about $\frac{1}{8}$ inch, or about $\frac{1}{3}$ of the thickness of the pipe. These are the small ones. The larger pittings are very shallow.

We feel that we have perhaps got about half, or perhaps a little more than half the life of the pipe at the present time. That is, we have had twenty-two years use of it so far, and we ought to get perhaps 15 or 20 years more.

PRESIDENT BARBOUR. Do you know what particular brand of asphalt was used?

MR. TAYLOR. No, but the specifications are:

"The coating consists of best quality of California or Trinidad refined asphalt, must be durable, smooth, glossy, hard, tough, perfectly water proof and not affected by any salts or acids found in the soil, strongly adhesive to the metal, no tendency to become soft enough to flow when exposed to the sun in summer or become so brittle as to scale off in winter. Pipes thoroughly cleaned inside and outside and rust removed by brushing and scrubbing with a wire brush and diluted acid, followed by mopping or brushing with milk of lime or saturated solution of soda. The alkali used to be washed off and surface dried. Coating heated to temperature of about 300 degrees and pipes dipped, allowed to dry, then dipped again."

MR. HENRY A. SYMONDS.* Mr. President.—There are a few construction difficulties that I remember in connection with the 42-in. lock-bar steel pipe line built for the City of Springfield, about twelve years ago, on which Mr. Hazen was Consulting Engineer.

These matters perhaps did not come so much to the attention of the Engineering Department as they did to those of us in the Construction Department.

Regarding coating, the pipe had been dipped into a hot bath of melted pitch. When this was raised out of the pitch, it being immersed vertically, subsequent developments indicated that, on an occasional pipe, the hot pitch flowed to the lower section, leaving the upper as thin as tissue paper in some cases, while it was heavy and adhered tenaciously to the metal at the bottom.

The pipe was retouched by melting pitch and burning it in with a blow torch where the skid marks referred to by Mr. Liesen, occurred, but the difficulty relative to interior coating was not apparent until the pipe was laid in the trench.

It required going over the line several times, painting sections here and there, with hot pitch burned in by blow torch, before the trouble was entirely taken care of.

* Consulting Engineer, Boston, Mass.

Another difficulty which we had frequently in the actual construction, occurred in the sandy plains near West Springfield. Frequent spurts occurred from the riveted joints, and some of them remained even after calking. These spurts with the fine sand driven against the side of the pipe, in several cases cut grooves entirely through the metal. In some cases, I think, in less than twenty-four hours from the time water was turned on. In two cases long sections of pipe, laid through hollows, floated by the trench being flooded in a heavy storm, and the trench was washed partly full of gravel. As these sections had been riveted and calked it was a very different matter to get them back to grade.

Another difficulty which I think we barely escaped through good fortune, which has occurred in some other lines, was the collapsing of the pipe before the air valves were properly in place. There were 6-inch gates, which were to later receive regular air valves, for taking air into or allowing it to escape from the pipes, but during the testing period the plates pulled out of the lock-bar at one point for about 6 feet. That, by the way, was the only break that occurred in the twelve miles. I think this was under a pressure of something like 190 pounds. It occurred at a very low level as compared with much of the line, and the speaker happened to be near and opened one of these 6-inch valves. The whistling which occurred was equal to that of a locomotive, and continued probably for fifteen minutes, in which time the pipe was rapidly emptied. There was probably a mile and a half which was emptied by this break.

Those are perhaps the principal difficulties which we encountered in that construction. But I want to say that any one who starts to lay steel pipe and tries to use the methods employed in laying cast-iron pipe will find himself up against a great many troublesome problems.

MR. TAYLOR. I might add to the New Bedford situation that we frequently test that pipe for leaks and have so far found it absolutely tight. Also at one time we were threatened with trouble from electrolysis and cured that by putting in a copper bolt and leading a wire back to the negative bus.

MR. J. E. GARRETT.* To get back to the question of electrolysis, did I understand Mr. Phillips to say that in Akron the water pipes system was bonded to one of these substations, to the substation that was located centrally in Akron?

MR. PHILLIPS. Yes.

MR. GARRETT. And has that bond been continued?

MR. PHILLIPS. So far as I know it is still there.

MR. GARRETT. The pipe being lead or cast-iron pipe?

MR. PHILLIPS. Yes.

PRESIDENT BARBOUR. I would suggest to Mr. Liesen, if he is going to write a paper on steel pipe, that one of the great necessities of the present time is to so control the heating preliminary to dipping as to obtain a

* Civil Engineer, Hartford, Conn.

uniform temperature. As I have already stated, the reason that tar was given up on the Akron line was due to failure to obtain such uniform heating. Through the coöperation of Mr. Church of the Barrett Company, one of the best tar chemists in this country, it was proved that the temperature in the pipes, as made for Akron, varied from, say, 250° F. on one side to perhaps 500° F. on the other side of the same pipe, and a coating under these conditions might be soft on one side of the pipe and brittle on the other.

Recently, in connection with the work of the Committee on Standard Specifications for Cast-Iron Pipe, I have had some correspondence with Mr. Church in regard to a specification which would guarantee the use of a straight run coal tar, and his position is practically this, that until we are able to better control the temperature of the cast-iron pipe at the time of dipping it is useless to spend much time in the refinement of the specifications for tar.

Mr. G. F. Sever. Mr. President, I do not have the honor of belonging to your Association, but I have been requested by Professor O. C. Jackson, who was invited to discuss this paper, to attend this meeting. I am an electrical engineer, and it is very interesting to me to see that electricity does not appear to be the scapegoat that it sometimes has been made in water works investigations.

Water Works Engineers have recommended that the electric railroads, on account of the alleged electrolytic damage caused by the current, be compelled to put up double overhead trolley lines and remove their currents entirely from the rails. I am very glad to see now that there are recognized other means causing the destruction of steel and cast iron pipes than our electric railway currents.

I have investigated the corrosion of pipes in Richmond, Va., Dayton, O., Peoria, Ill., and in the vicinity of Philadelphia, in Trenton and other places. I have found water and gas pipes and also Edison tubes which have been treated, lying in certain kinds of soil, particularly with a cinder content, which have been entirely corroded through and destroyed purely from the chemical actions that occurred. And I have had occasion to investigate in the outskirts of Philadelphia an iron gas pipe which was treated at the gas works by a covering of tar and paper,—three layers of paper, each one dipped in a tar compound — and laid in a marshy soil, far removed from the electric railroad. The gas company claimed that the electric railway current was the cause of the continuous destruction of this iron gas pipe. Tests on the electric railroad in that vicinity showed no possibility of any current flow on this gas main, and by applying electrical instruments to the gas main there was found no electric railway current, but the gas main would last possibly two or three months and have to be continually replaced by other and new pipe. Moisture seemed to permeate the covering and localize chemical action on the pipe.

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Recently I have had occasion to investigate a large water conduit in the State of Maine. It was of cast-iron and fed a large city. We were called in to make tests on it, to see if there was any possibility of electrolysis caused by the current from a suburban electric railroad. The pipe in this case I believe has been laid 16 or 18 years, and in uncovering it near the railroad we found the asphalt covering absolutely intact. The pipe was lying in a moist soil and we had to scrape the covering from the pipe in order to attach to it by solder a couple of leads for an electrical recording instrument. We observed the pipe at this location through its full length, and all about it, and could not see any deterioration of the protective covering.

In regard to the remarks of the author of the second paper about the action of the electric railroad in analyzing and making an economic study of their electric supply system, I would say that I have had occasion to lay out a number of return feeder systems for electric railroads, and have recommended the absolute taking away of any connection between water supply systems and the negative bus of the railroad, have introduced many negative feeders in order to relieve the rails and pipes of their high electric potentials and have recommended over and over again automatic substations at short intervals in order to reduce the potentials that normally obtain on suburban and interurban railroad systems where the substations are now possibly three to six miles apart, with the ordinary 600 volt direct current system.

So that in almost all cases where there has been any trouble — at least, in recent years—the railroads are endeavoring to remedy the troubles, to mitigate them, and, if possible keep the water supply systems as far away from the railway system and the return feeders as is possible.

PROPOSED EXTENSION OF THE METROPOLITAN WATER DISTRICT.

BY X. H. GOODNOUGH.*

(*February 14, 1923.*)

Under the provisions of Chapter 49 of the Resolves of the year 1919, the State Department of Health and the Metropolitan Water and Sewerage Board, which is now the Metropolitan District Commission, were directed to consider the water supply needs and resources of the State with special reference to the requirements of certain districts, most important among which is the Metropolitan Water District, created by Chapter 488 of the Acts of the Year 1895.

The first questions to be determined were the present needs of the district and its probable future requirements, and these questions have involved a study of past growth in population and in the use of water. The problem of the population of this district 25 or 50 years hence is of course an insolvable one, and the only safe ground of estimate is to assume that its future growth will continue about as past experience indicates. The original report of the State Board of Health in 1895 recommended a district of 28 cities and towns which contained, in 1890, a population of 848 012 inhabitants. The State Board of Health stated in that report however, that "inasmuch as the cities of Cambridge, Lynn, Newton, Waltham and Woburn and the towns of Brookline, Lexington, Nahant, Saugus, Swampscott and Winchester, together containing, in 1890, 210 252 inhabitants, believe that they have a sufficient supply for some years to come, we do not recommend that they be provided with water from the Metropolitan supply until they formally express their wish for it." The exclusion of these places left 17 municipalities which, it was recommended by the State Board of Health, should constitute the original district, but when the legislation was finally enacted only 13 municipalities were included and that number has since been reduced by the annexation of the town of Hyde Park to the city of Boston. But since the district was formed in 1895 it has been enlarged by the addition of the city of Quincy and the towns of Arlington, Lexington, Milton, Nahant, Stoneham and Swampscott, so that it contains at the present time 19 cities and towns which had in 1895 a population of 763 417. At the end of 1920 the population of this group of municipalities was 1 252 903. The total quantity of water consumed in this district in 1895 was about 69 000 000 gal. per day, and the quantity used in 1920 was 131 000 000 gal. per day, or nearly double the amount used 25 years earlier.

* Director and Chief Engineer, Mass. State Dept. Public Health.

Estimated Population to be Supplied.

A study of the census records shows that the population of the Metropolitan Water District has doubled in the past 32 years. The percentage of growth of the district has been a very steady one. Taking the progressive 30-year increases, it is found that in 30-year periods beginning with the period 1850–1880 and including the period 1885–1915, the increase has ranged from 103.5 to 123.3 per cent; that is, in each of these periods the population has more than doubled in 30 years. In the period which included the recent war, however, there was a decided reduction in the rate of growth, the increase falling from 115.9 per cent in the period 1885-1915 to 89.1 per cent in the period 1890–1920. Of course this falling off was largely if not wholly due to the war, but in estimating the future percentage of growth it has been assumed that this percentage will continue to be a declining one, approximately as shown in the following table.

Table showing Percentage of Population Increase by Thirty-Year Periods, with Estimates for 1920 to 1970.

METROPOLITAN DISTRICT, INCLUDING NEWTON.

Period.	Per Cent Increase.	Period.	Per Cent Increase.
1850–1880	123.6	1895–1925	81.2
1855–1885	103.6	1900–1930	73.0
1860–1890	109.6	1905–1935	73.6
1865–1895	123.3	1910–1940	66.8
1870–1900	124.2	1915–1945	59.8
1875–1905	103.5	1920–1950	63.8
1880–1910	113.7	1925–1955	58.0
1885–1915	115.9	1930–1960	52.9
1890–1920	89.1	1935–1965	48.8
		1940–1970	45.1

Using this lesser rate of increase, the future population of the district would be about as shown on the accompanying diagram. On this diagram (No. 1) are shown the actual growth in population from 1870 to 1920 and the estimated growth to 1970. The diagram also shows the future population of the cities and towns now comprising the Metropolitan Water District as estimated in the report of 1895, those estimates having been based on the growth of population up to 1890. The diagram shows that the actual increase in population varied but little from the estimates during the first years — 1890 to 1900 — but from 1900 to 1905 there was a falling off, and then from 1905 to 1915 the lines are nearly parallel. Up to 1915 the estimate of population made by the State Board of Health based on the censuses previous to 1890 exceeded the actual by about 10.9 per cent. Of course in the war period from 1915 to 1920 there was a decided decrease in the growth of the district as in New York and other places, but even in 1920 the difference between the actual and estimated growth based on censuses of 30 years earlier was less than 20 per cent.

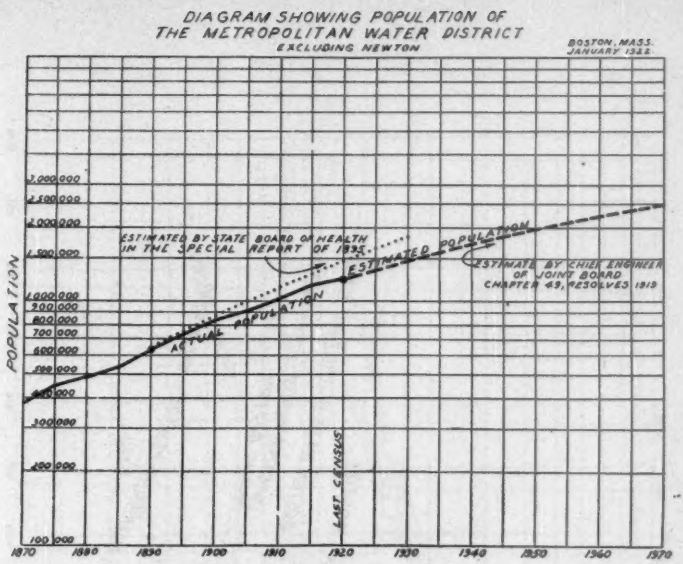


DIAGRAM NO. 1.

The growth of the different parts of the district also shows considerable variation as indicated on diagram No. 2. The area of the city of Boston is only some 40 odd square miles, and the rate of growth is lessening as the density of population becomes greater. The portion of the district exclusive of the city of Boston is growing more rapidly than the city itself and there is still a large population outside the district which is showing a steady and rapid growth.

On diagram No. 3 is shown a comparison between the growth of the Metropolitan Water District and of the city of Boston, as compiled by the U. S. Census Bureau, and that of the other great metropolitan centers, of which there are now five in the United States that have a population in excess of one million inhabitants. A study of this diagram shows in the first place that the growth of the city of Chicago was much the most rapid of all for many years but that this rate has in later years diminished and in recent years has been but a little, if any, greater than that of the two cities next in size — Philadelphia and Boston. Compared with Philadelphia, the Boston district grew more rapidly on the whole up to 1915, but its rate of growth was curtailed during the period of the war. The city of Pittsburgh, next to Chicago, has grown at a very rapid rate, but since 1910 its rate of growth has been somewhat less than that of Boston or Philadelphia. The city of New York has grown in recent years more rapidly than the others, though, like Boston, the rate was seriously diminished in the last census period on account of the war. Leaving out the war period, which affected the dif-

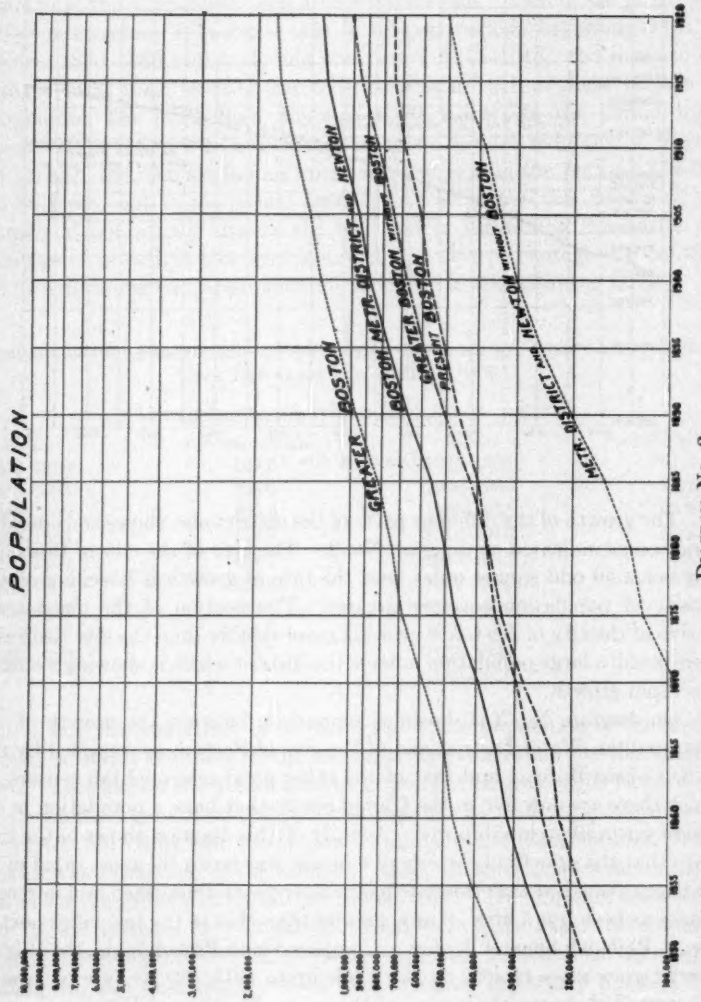

POPULATION
GREATER BOSTON
BOSTON METR. DISTRICT and NEWTON
GREATER BOSTON without BOSTON
PRESENT BOSTON
METR. DISTRICT and NEWTON without BOSTON

DIAGRAM No. 2.

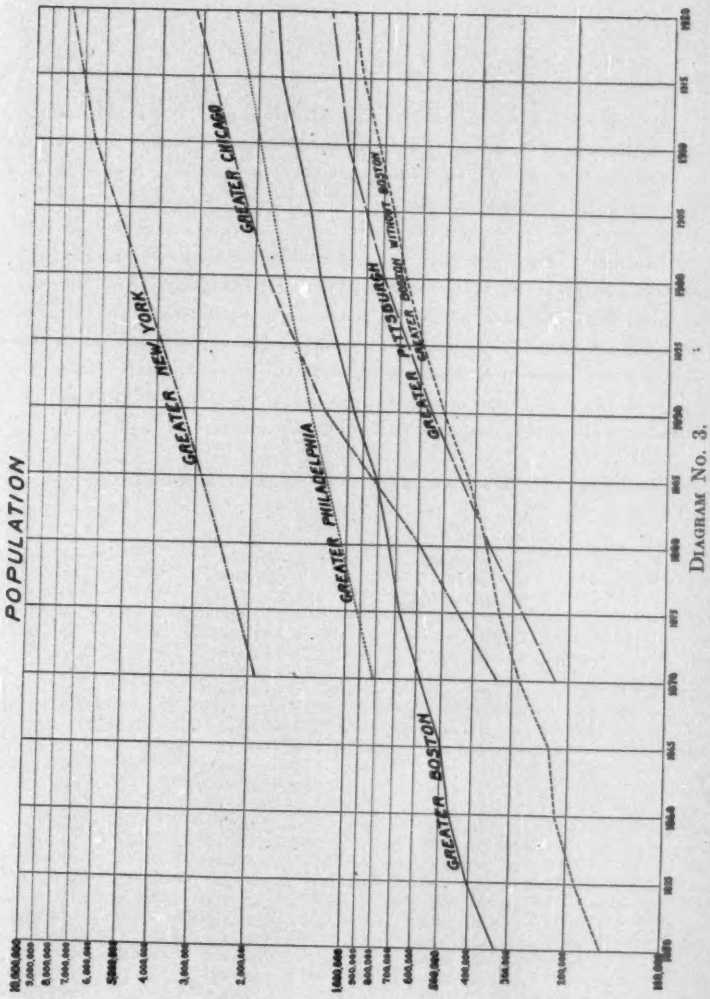

POPULATION
GREATER NEW YORK
GREATER CHICAGO
GREATER PHILADELPHIA
GREATER PITTSBURGH
GREATER BOSTON WITHOUT BOSTON
GREATER BOSTON

DIAGRAM No. 3.

ferent cities in different ways, there is nothing in this record to indicate that the growth of the metropolitan district of Boston is not keeping pace with that of the other great metropolitan centers. Obviously prudence requires that allowance must be made for a rate of growth in the future which shall follow the general curve indicated by the experience of previous years.

Water Consumption in the Metropolitan Water District.

The quantity of water used in the Metropolitan Water District, exclusive of the city of Newton, in 1920 was 127 265 000 gal. per day, or 105.5 gal. to each inhabitant. Including the city of Newton, the total consumption was 130 952 000 gal. per day, or 104.5 gal. per person per day, but the City of Newton provided its entire water supply during the year from its own sources. The aggregate amount of water used in the municipalities which now compose the Metropolitan Water District, excluding the city of Newton, in 1894, the year before the district was established, was 63 759 000 gal. per day, or 89 gal. per inhabitant; that is, the consumption of water in the district, exclusive of Newton, doubled in the 26 years from 1894 to 1920. The consumption of water in the District and in the City of Newton in each year from 1893 to 1920 is shown in the following table:

Average Daily Water Consumption, Metropolitan Water District.

Year.	Metropolitan Water District.	Newton.	Total.
1893	64 795 000	1 370 000	66 165 000
1894	63 759 000	1 623 000	65 382 000
1895	67 698 000	1 801 000	69 499 000
1896	76 548 000	1 812 000	78 360 000
1897	78 989 000	1 804 000	80 793 000
1898	81 893 000	1 758 000	83 651 000
1899	90 075 000	2 036 000	92 111 000
1900	95 973 000	2 086 000	98 059 000
1901	102 802 000	1 843 000	104 645 000
1902	108 418 000	1 927 000	110 345 000
1903	108 168 000	2 109 000	110 277 000
1904	114 937 000	2 188 000	117 125 000
1905	117 757 000	2 151 000	119 908 000
1906	118 567 000	2 223 000	120 790 000
1907	125 307 000	2 318 000	127 625 000
1908	126 479 000	2 444 000	128 923 000
1909	120 240 000	2 344 000	122 584 000
1910	113 239 000	2 505 000	115 744 000
1911	110 907 000	2 583 000	113 490 000
1912	116 231 000	2 732 000	118 963 000
1913	103 848 000	2 889 000	106 737 000
1914	107 036 000	2 960 000	109 996 000
1915	101 942 000	2 830 000	104 772 000
1916	106 338 000	3 099 000	109 437 000
1917	110 032 000	3 121 000	113 153 000
1918	129 764 000	3 426 000	133 190 000
1919	120 594 000	3 488 000	124 082 000
1920	127 265 000	3 687 000	130 952 000

Records from 1893–1903, inclusive, based on pumpage records.
Records from 1904 to date, inclusive, based on meter records.
Records from 1893–1908, inclusive, include small amount of water supplied by Revere to Saugus (this amount not included after 1908).

After the establishment of the district the consumption of water per inhabitant rose very rapidly until 1904, when it reached 128 gal. per capita at a time when the number of metered services in the district was about 11 per cent of the total. Following 1904 the more liberal use of meters was begun in the cities and towns in the district outside the city of Boston, and whereas in 1904 only 19 per cent of the services were metered in these municipalities, by 1908 the per cent of metered services had risen to 47.6 and the number continued to rise to 85.7 per cent in 1915 and 91.1 per cent in 1920. In the city of Boston 6.5 per cent of the services were metered in 1908, 53.1 per cent in 1915 and 62.5 per cent in 1920. In the district as a whole, excluding Newton, the percentage of metered services rose from 10.8 per cent in 1904 to 21.8 per cent in 1908, to 66.6 per cent in 1915 and 74.6 per cent in 1920. It will be seen that, following the legislation in 1907 requiring the general application of meters on all services, the introduction of meters rapidly followed and the consumption per capita in the district as a whole fell from 130.4 gal. in 1907 to 88 gal. in 1915, the latter amount being slightly less than the quantity used in the same municipalities in 1894. This great and rapid reduction in the use of water per capita by means of the general application of meters appeared to solve the problem of waste prevention, a subject which has engaged the serious attention of water works authorities since water works were first introduced; but following the small quantity of water used in 1915 — 88 gal. per capita — which was unquestionably due to a combination of causes all operating to produce a minimum use of water, the consumption of water per capita again began to rise and amounted in 1920 to 105.5 gal. per day. In one of these years, 1918, the amount of water used per capita rose to 109.3 gal. per day in consequence of an unusually cold winter. These changes are shown in the following table and on diagram No. 4.

In the city of Boston the percentage of metered services is less than in the district as a whole, amounting in 1920 to 62.5 per cent while in the district outside of Boston the percentage of metered services in 1920 was 91.1 per cent, but the experience has been practically the same in all of the municipalities composing the district, viz., a great rise in the consumption of water per capita following the creation of the district and a great reduction during the period of the introduction of meters, which continued until 1915 when 66.6 per cent of the services had been metered. After that year the consumption of water again began to rise and has continued to rise though the percentage of metered services has increased from 66.6 to 74.6 per cent.

In view of this marked increase in the consumption of water in the last few years, notwithstanding the general use of meters in the district, it has been deemed important to collect information as to the conditions existing in other cities where the meter system has been in use for any considerable length of time. In connection with this question, information has been obtained from all of the large northern cities of the United States

TABLE SHOWING POPULATION, PER CENT OF METERED SERVICES AND PER CAPITA DAILY CONSUMPTION IN GALLONS IN BOSTON AND THE METROPOLITAN WATER DISTRICT.

	Metropolitan Water District.						Boston.			Metropolitan District Minus Boston.					
	Including Newton.			*Excluding Newton*						*Including Newton.*			*Excluding Newton.*		
Year	Population.	Per Cent. Met'r'd	Per Capita Con.	Population.	Per Cent Met'r'd	Per Capita Cons.	Population.	Per Cent Met'r'd	Per Cap. Cons.	Population.	Per Cent Met'r'd	Per Cap. Cons.	Population.	Per Cent Met'r'd.	Per Cap. Cons.
1904	936 861	14.4	125.0	900 682	10.8	127.6	602 739	5.9	147.2	334 122	27.0	85.1	297 943	19.0	88.1
1905	951 641	16.0	126.2	914 814	12.5	128.8	609 890	6.1	149.0	341 751	30.5	85.0	304 924	23.0	88.2
1906	975 434	18.5	123.9	938 011	15.1	126.5	625 130	6.3	147.2	350 304	36.2	82.2	312 881	29.5	84.9
1907	999 237	21.0	127.7	961 218	17.7	130.4	640 371	6.4	152.4	358 866	42.1	83.7	320 847	36.2	86.4
1908	1 023 010	24.9	126.0	984 396	21.8	128.4	655 611	6.5	151.6	367 399	52.4	80.3	328 785	47.6	82.3
*1909	1 046 493	31.4	117.1	1 007 283	28.6	119.3	670 852	12.9	141.8	375 641	57.3	73.1	336 431	53.4	74.5
1910	1 070 256	40.0	108.2	1 030 450	37.5	109.9	686 092	20.7	129.0	384 164	66.7	71.0	344 358	63.8	71.9
1911	1 096 466	47.7	103.5	1 055 999	45.5	105.0	697 962	28.1	123.9	398 504	74.4	67.8	358 037	72.3	68.2
1912	1 122 675	53.7	106.0	1 081 546	51.7	107.5	709 831	34.8	126.8	412 844	79.1	70.4	371 715	77.5	70.5
1913	1 148 881	59.2	92.8	1 107 091	57.6	93.9	721 700	41.4	110.0	427 181	82.7	64.1	385 391	81.7	63.5
1914	1 175 091	63.9	93.6	1 132 639	62.5	94.6	733 570	47.4	111.6	441 521	85.2	63.7	399 069	84.5	63.0
1915	1 201 300	67.8	87.2	1 158 187	66.6	88.0	745 439	53.1	104.2	455 861	86.3	59.5	412 748	85.7	58.8
1916	1 211 618	71.8	90.4	1 167 917	70.8	91.1	745 936	58.3	107.7	465 682	88.6	62.4	421 981	87.9	61.6
1917	1 221 941	73.3	92.6	1 177 652	72.2	93.5	746 433	59.9	110.0	475 508	89.8	65.4	431 219	89.0	64.9
1918	1 232 261	73.6	108.1	1 187 383	72.4	109.3	746 929	59.9	126.7	485 332	90.3	79.5	440 454	89.5	79.8
1919	1 242 586	74.4	99.8	1 197 120	73.3	100.7	747 426	60.5	119.9	495 160	91.1	69.5	449 694	90.4	68.8
1920	1 252 903	75.6	104.5	1 206 849	74.6	105.5	748 060	62.5	126.0	504 843	91.3	72.6	458 789	91.1	71.9

* Prior to 1909 the water consumption of Revere includes that of a small part of Saugus and consequently prior to that year the estimated population of the part of Saugus supplied has been added. This amounts to only 200-280 persons.

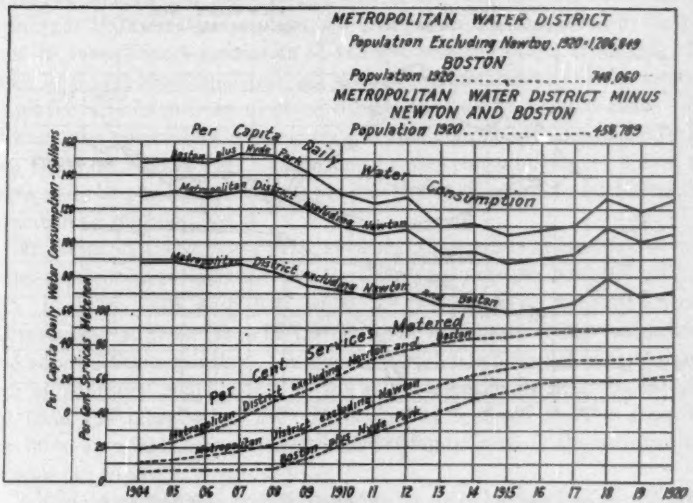

METROPOLITAN WATER DISTRICT
Population Excluding Newton, 1920-1,206,849
BOSTON
Population 1920 748,060
METROPOLITAN WATER DISTRICT MINUS NEWTON AND BOSTON
Population 1920 458,789
Per Capita Daily Water Consumption
Boston plus Hyde Park
Metropolitan District including Newton
Metropolitan District including Newton and Boston
Per Capita Services Metered
Per Cent Services Metered
Metropolitan District excluding Newton and Boston
Metropolitan District excluding Newton
Boston, plus Hyde Park
1904 05 06 07 08 09 1910 11 12 13 14 1915 16 17 18 19 1920

DIAGRAM NO. 4.

east of the Rocky Mountains where climatic conditions are similar to those at Boston. In this territory there are 13 cities, exclusive of the Boston Metropolitan District, having by the census of 1920 a population in excess of 400 000. The records of the consumption of water per capita in each of these cities, together with the percentage of services metered, has been furnished by city officials, the information covering in most cases periods as long as 30 years. From these records it appears that in 5 of these cities over 90 per cent of the services are metered, while in all of the other cities, the percentage of metered services is less than in the Metropolitan Water District; these 5 cities and the percentage of services metered in each in 1920 are shown in the following table;

Detroit	97 per cent.
Cleveland	100 per cent.
Milwaukee	99 per cent.
Cincinnati	99 per cent.
Newark	92 per cent.

In this list of cities the application of meters to services generally has been so recent in two of the cities — Detroit and Cincinnati — that little information is furnished by their experience as to the changes in the consumption of water after two-thirds to three-fourths of the services have been metered.

The accompanying diagrams Nos. 5 and 6 show the per capita consumption and the per cent of metered services in these 5 cities, so far as the records of consumption are available.

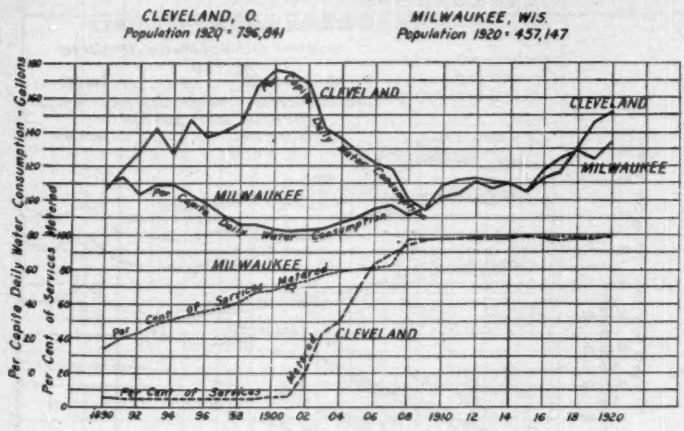

CLEVELAND, O.
Population 1920 = 796,841
MILWAUKEE, WIS.
Population 1920 = 457,147
Per Capita Daily Water Consumption - Gallons
Per Cent of Services Metered
CLEVELAND
MILWAUKEE
Per Capita Daily Water Consumption
Per Cent of Services Metered
1890 92 94 96 98 1900 02 04 06 08 1910 12 14 16 18 1920

DIAGRAM No. 5.

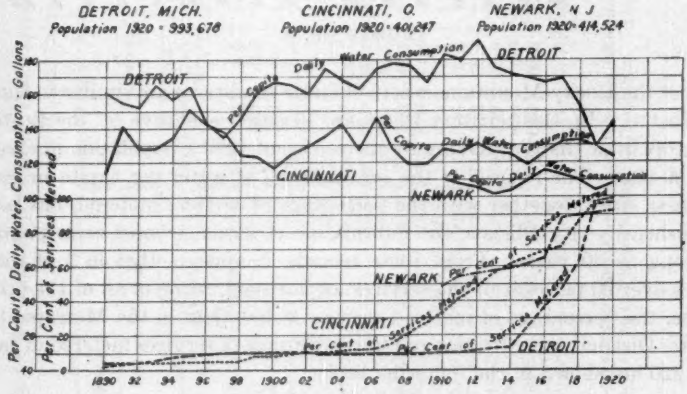

DETROIT, MICH.
Population 1920 = 993,678
CINCINNATI, O.
Population 1920 = 401,247
NEWARK, N J
Population 1920 = 414,524
Per Capita Daily Water Consumption - Gallons
Per Cent of Services Metered
DETROIT
CINCINNATI
NEWARK
1890 92 94 96 98 1900 02 04 06 08 1910 12 14 16 18 1920

DIAGRAM No. 6.

In Cleveland the general introduction of meters was begun about 1900 when less than 10 per cent of the services had been metered and the consumption per capita was 176 gal. The amount of water used per capita decreased rapidly as the number of meters increased until in 1905, when 68 per cent of the services had been metered, the consumption per capita had fallen to 128 gal. It continued to fall for 4 years more until in 1909 when it amounted to 94 gal. with 97 per cent of the services metered. Since 1909 with over 97 per cent of the services metered the consumption of water per capita has again risen and amounted to 152 gal. in 1920.

In Milwaukee the experience has been similar to that of Cleveland. A high per capita consumption of water was reduced by the general intro-

duction of meters, and when 72 per cent of the services had been metered in the year 1901 the consumption of water per capita had fallen in the previous 10 years from a maximum of 113 gal. to a minimum of 82 gal. Between 1901 and 1909 practically all of the remaining services were metered and all services have been metered during the last 11 years. Since 1901, however, the consumption per capita in this completely metered city has risen from 82 to 134 gal. Variations in the consumption of water per capita and the percentage of metered services in Cleveland and Milwaukee are shown on diagram No. 5.

In Newark, in the years 1912, 1913 and 1914, when at least 56 per cent of the services were metered, the average consumption was 104 gal. per day. In 1918, 1919, and 1920, when the percentage of metered services had increased to from 90 to 92 per cent, the per capita consumption averaged about 107 gal. per day. While the period has been too short a one to form satisfactory conclusions, so far as the records show up to the present time the increase in the percentage of metered services from less than 60 to over 90 has been accompanied by an increase in the consumption of water per capita.

Information has also been collected from cities having less than 400 000 inhabitants in 1920, in which a large percentage of the services are metered. The number of such cities from which records have been obtained which have a population in excess of 25 000, including 9 in Massachusetts, is 19; and in addition there are 3 other cities in which from 75 to 85 per cent of the services were metered in 1919 or 1920. The per capita consumption and the percentage of services metered in practically all of these cities are shown in diagrams Nos. 7, 8, 9, 10, 11, 12.

Diagram No. 13 shows the consumption of water per capita and the per cent of metered services in a residential district comprising Brookline, Newton, Needham and Wellesley, containing in 1920 a population of 97 038, — these municipalities being adjacent to the Metropolitan Water District and one of them, the city of Newton, a member of the district, though that city does not take water from the district sources at the present time.

The experience in the various cities following the general metering of the services as presented in the diagrams shows that in a great majority of cases the general introduction of meters in a city in which few meters have previously been in use has been followed by a large reduction in the use of water per capita. The experience in the Metropolitan Water District in this respect is duplicated in practically all of the cities for which records have been obtained. But the diagrams also indicate clearly that in the great majority of these cases after two-thirds or more of the services had been metered the consumption of water per capita sooner or later began again to increase and has continued to increase up to the present time, notwithstanding the continued application of meters until most or all of the services have been metered.

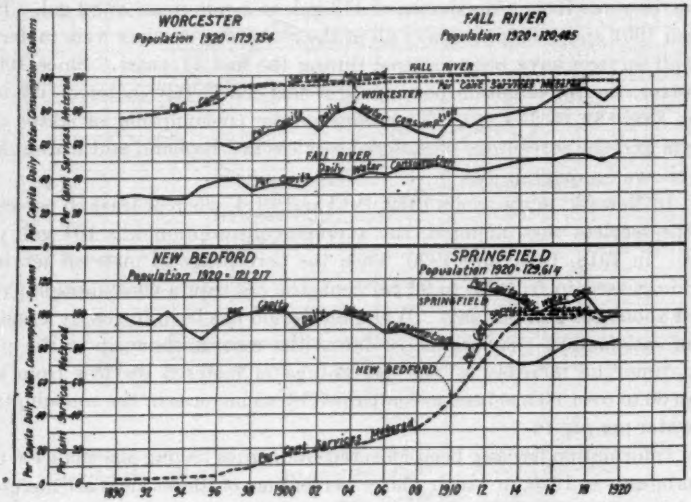

WORCESTER
Population 1920 - 179,754
FALL RIVER
Population 1920 - 120,485
NEW BEDFORD
Population 1920 - 121,217
SPRINGFIELD
Population 1920 - 129,614
Per Capita Daily Water Consumption - Gallons
Per Cent Services Metered
1890 92 94 96 98 1900 02 04 06 08 1910 12 14 16 18 1920

DIAGRAM No. 7.

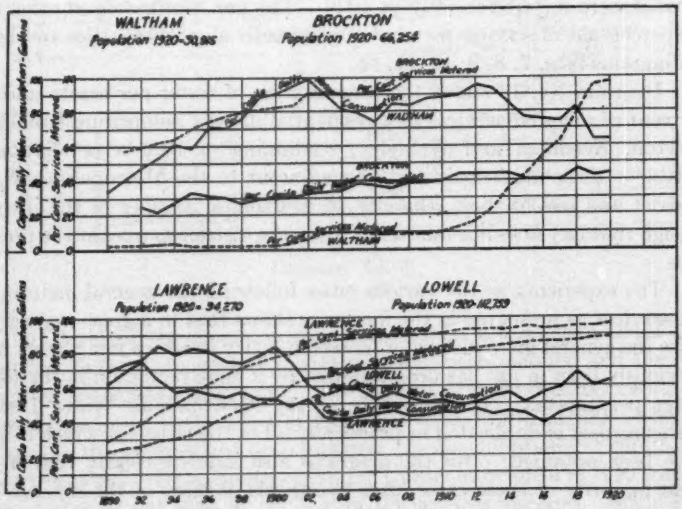

WALTHAM
Population 1920 - 30,915
BROCKTON
Population 1920 - 66,254
LAWRENCE
Population 1920 - 94,270
LOWELL
Population 1920 - 112,759
Per Capita Daily Water Consumption - Gallons
Per Cent Services Metered
1890 92 94 96 98 1900 02 04 06 08 1910 12 14 16 18 1920

DIAGRAM No. 8.

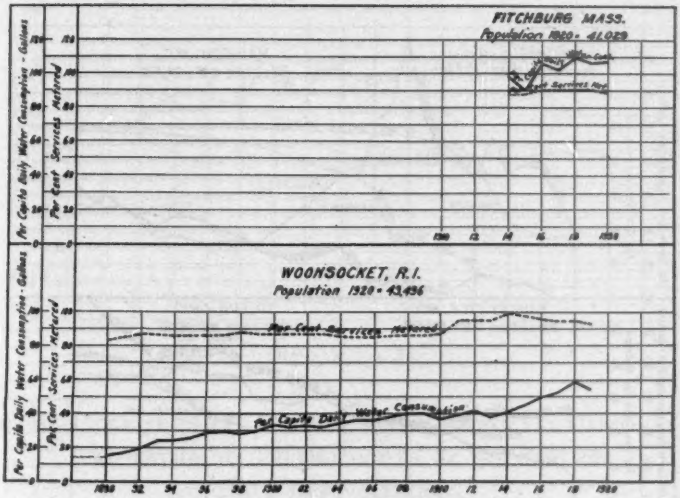

FITCHBURG MASS.
Population 1920 = 41,029
Per Capita Daily Water Consumption - Gallons
Per Cent Services Metered
WOONSOCKET, R.I.
Population 1920 = 43,496
Per Cent Services Metered
Per Capita Daily Water Consumption

Diagram No. 9.

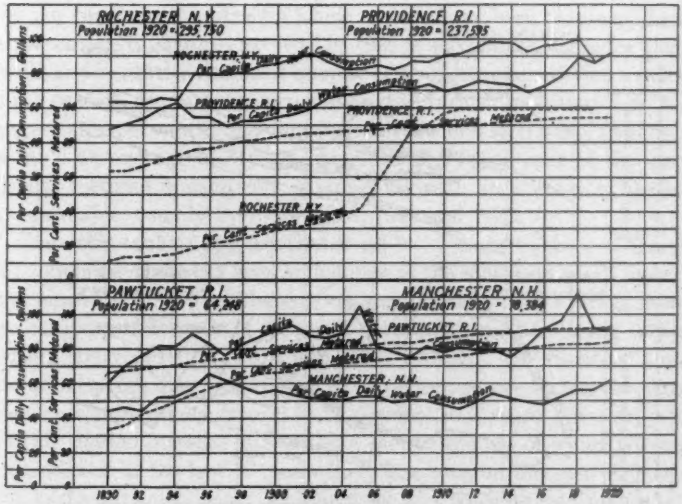


Diagram No. 10.

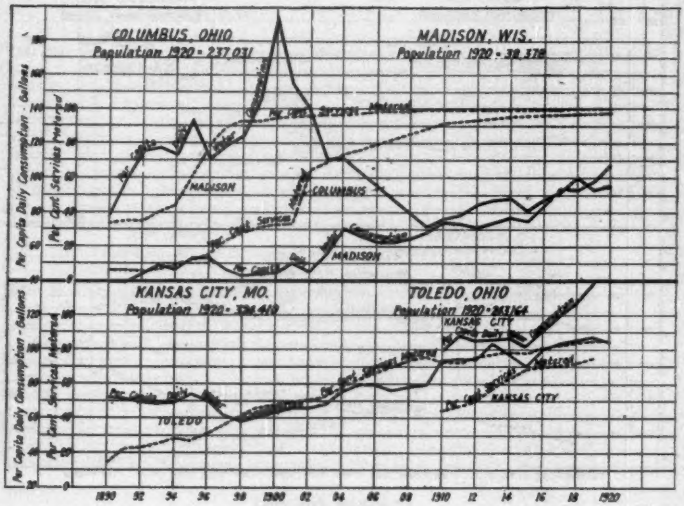

COLUMBUS, OHIO
Population 1920 - 237,031
MADISON, WIS.
Population 1920 - 38,378
KANSAS CITY, MO.
Population 1920 - 324,410
TOLEDO, OHIO
Population 1920 - 243,164
Per Capita Daily Consumption - Gallons
Per Cent Services Metered
1890 92 94 96 98 1900 02 04 06 08 1910 12 14 16 18 1920

DIAGRAM NO. 11.

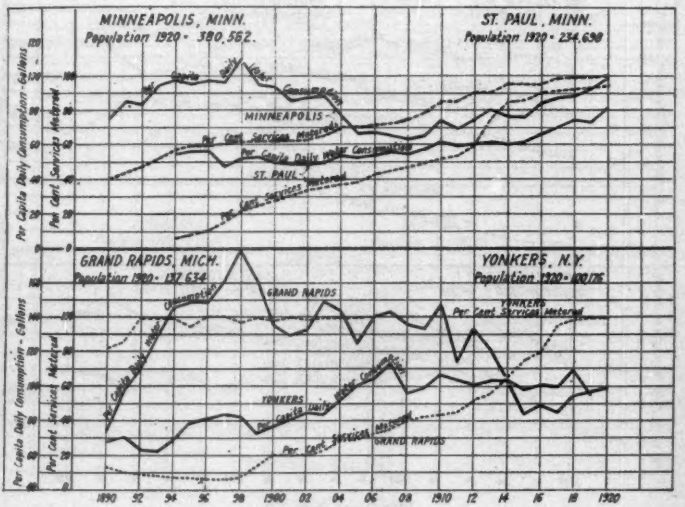

MINNEAPOLIS, MINN.
Population 1920 - 380,582.
ST. PAUL, MINN.
Population 1920 - 234,698
GRAND RAPIDS, MICH.
Population 1920 - 137,634
YONKERS, N.Y.
Population 1920 - 100,176
Per Capita Daily Consumption - Gallons
Per Cent Services Metered
1890 92 94 96 98 1900 02 04 06 08 1910 12 14 16 18 1920

DIAGRAM NO. 12.

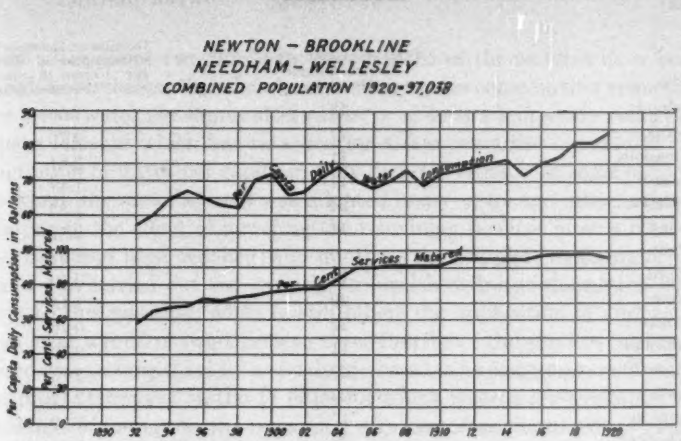


DIAGRAM NO. 13.

GENERAL INCREASE IN THE CONSUMPTION OF WATER PER CAPITA AFTER TWO-THIRDS TO THREE-FOURTHS OF THE SERVICES HAVE BEEN METERED.

In this study the object has been to learn what changes have taken place in the consumption of water per capita after two-thirds to three-fourths of the services have been metered, as is the case in the Metropolitan Water District. The table on page 204 shows the changes in the use of water per capita in the cities for which records have been obtained in which the percentage of metered services in 1920 is substantially greater than 75 per cent and in which a sufficient number of years has elapsed after a substantial per cent of the services were metered to furnish information as to the changes in the per capita consumption with the increased use of meters. In this table an average of 3 years, when about 74 per cent of the services had been metered in each city, is compared with an average of the last 3 years available, usually the years 1918, 1919 and 1920.

From this table it appears that in all but 2 cases — those of Hartford and Lawrence—there has been an increase in the consumption of water per capita since 75 per cent of the services were metered; the average increase when comparison is made of the years 1918, 1919 and 1920 being 1.42 gal.; or, using the years 1917, 1918 and 1919, 1.31 gal. In Hartford the full effect of metering does not appear to have been secured when the number of meters was increased from 6 to 71 per cent in 3 years. For some time after this sudden increase in the use of meters the use of water per capita decreased, but in the last 13 years there has been an increase of 0.38 of a gallon per capita per year. In Lawrence the consumption of water per capita since 1900, when more than 75 per cent of the services were metered, has decreased 0.2 of a gallon per person per year; but since becoming more

City.	Years since about 75% Services became Metered.	Increase or Decrease in Consumption of Water per Capita in those Years (Gals. per Year).
Cleveland	13	1.59
Milwaukee	17	2.70
Minneapolis	11	2.61
Rochester	11	1.48
Providence	24	1.33
Toledo	11	2.52
St. Paul	6	2.61
Hartford	18	−0.50
Yonkers	29	1.15
Pawtucket	22	0.79
Manchester	11	0.73
Atlantic City	20	3.73
Madison	23	2.12
Burlington	17	1.10
Woonsocket	28	1.42
Worcester	23	1.26
Fall River	29	0.80
Lawrence	20	−0.32
Lowell	12	0.86
New Bedford	7	0.57
Brockton	23	0.57
Fitchburg	5	2.07
Average		1.42*

Yonkers, N. Y. — Records begin 1890 with 82% metered services.
Woonsocket, R. I.— Records begin 1890 with 83% metered services.
Fitchburg, Mass. — Records begin 1914 with 87% metered services.
Worcester, Mass. — Records begin 1896 with 93% metered services.

than 90 per cent metered in 1910 the consumption of water has increased at the rate of 0.4 of a gallon per person per year. In Fall River after the percentage of metered services reached about 75 the increase in the consumption of water per capita in 30 years was 0.8 of a gallon per person per year. After meters had been applied to more than 90 per cent of the services the increase has been 0.61 of a gallon per year. Of all this group of cities the important ones which show a decrease in the consumption of water per capita are Newark, Lawrence and Hartford and, as already seen, even in these cases apparently after the full effect of metering had been experienced the consumption of water again increased.

In the more fully metered communities in the Metropolitan Water District outside of Boston there has also been an increase in the consumption of water per capita in the last 6 years. In the suburban municipalities of Brookline, Newton, Needham and Wellesley the increase since 70 per cent of the services became metered in 1896 has been about 0.8 of a gallon per person per year. But while as a general rule no further material reduction in the use of water per capita is effected by the complete metering of all the

*This average would be 1.31 if average of returns for 1917, 1918 and 1919 is used.

services after about two-thirds to three-fourths of the services have been metered, nevertheless there has been in many cases some further reduction in the use of water per capita afterwards; or at least a temporary reduction has been effected which has retarded for a few years the increase in the consumption of water per capita in fully metered cities. In some of these cases where the meter system was adopted many years ago information is lacking as to the effect of metering the remaining services after a total of 75 per cent had been reached; and in others the complete metering of the services was carried out too recently to furnish definite information with respect to this question; while in still others the application of additional meters after a total of two-thirds to three-fourths of the services had been metered was accompanied by a steady increase in the consumption of water per capita. However, in the 11 cities for which records are available, the application of meters to the remaining services, after two-thirds to three-fourths of the services had been metered, caused for a time a reduction in the consumption of water per capita. In these cities the amount of the reduction ranged from 1 to 18 gallons per capita and averaged 9 gallons, in periods ranging from 1 to 14 years and averaging 4½ years. After this period the consumption of water per capita again began to increase and returned to its earlier figure in from 2 to 12 years, except in the case of one small manufacturing city where the period amounted to 21 years. The length of this period of return averaged 8.6 years; or, if the city referred to were excluded, 7.4 years. It is to be noted that the reduction in the consumption of water per capita as shown in these cases usually followed a much greater previous reduction due to the application of meters up to two-thirds or three-fourths of the total number of services and was a continuation of that reduction. There is no case in which the consumption of water has later been reduced, after it had begun to increase, when two thirds to three-fourths of all the services were metered, as in the case of the Metropolitan Water District.

In general then, so far as these records show, the full effect of metering is reached after a total of about 75 per cent of the services have been metered, but the effect of applying meters to the remaining services in many cases is to effect a further reduction for a time and to delay for a few years the beginning of the increase in the consumption of water per capita after the application of meters has become nearly or quite complete. The practically invariable rule, however, is that after 75 per cent of the services have been metered the consumption of water again increases, and even in fully metered cities continues to increase in spite of the complete adoption of the meter system. This is no argument, of course, for not completing the metering of all services. Aside from the saving in water consumption, metering is the only equitable way in which to assess the charges for water; and without complete metering there will continue to be waste which might be prevented by the use of meters.

The results of this study as a whole show clearly that there has not

only been a decided increase in the use of water per capita after complete metering in great cities like Cleveland, Minneapolis, St. Paul and Providence, but also in small cities in all parts of the United States where climatic conditions are similar to those existing in the Metropolitan Water District.

Inquiry has also been made concerning the experience in English cities as to the changes taking place in the consumption of water per capita and the allowances which are being made therefor, the results of which are shown in the following table.

City.	Average Increase in Consumption-per Capita (U. S. Gallons per Year).	Number of Years included.
Bradford	0.8	1909–1918
Glasgow	0.4	1909–1920
Leicester	0.6	1908–1920
Manchester	0.5	1907–1920
Nottingham	0.4	1907–1920
London	0.8	1907–1920
Liverpool	0.6	1905–1919

It thus appears that what is true in American cities is also true in English cities, namely, that there is a continued increase in the consumption of water per capita, and in estimating for future requirements English engineers are providing for such an increase.

Causes of the Increase in Water Consumption.

The causes of this general increase in the per capita consumption of water are no doubt due in part to a gradually improving standard of living and to growth in business and industry. The number of water fixtures in dwelling houses has increased enormously in proportion to the population in the last 40 years. Every dwelling place is supposed to have at least one bath tub and many dwelling houses now have two or more.

Even with this increase in use, the domestic consumption in many cities is less than the amount used for manufacturing purposes. In some cases the amounts used for manufacturing are very large. In the city of Peabody, for example, where a special kind of manufacturing using large quantities of water has become established, the consumption of water, notwitstanding the fact that 90 per cent of the services are metered, has constantly risen until in 1920 it exceeded 200 gal. per capita. It has been impracticable to determine the relative quantities of water used for various purposes in the Metropolitan Water District, but the relative amounts drawn for various purposes in an industrial city are indicated by the following records of consumption in the city of New Bedford in 1920, kindly furnished by Mr. S. H. Taylor, Acting Superintendent of the Water Works.

	Cons. Per Capita (Gallons).	Per Cent of Total.
Domestic consumption	28	36
Manufacturing and mechanical uses	41	52
Testing, flushing, fountains and all other purposes, including fires,	9	12
Total	78	100

In residential sections of the Metropolitan Water District the consumption of water per capita is probably larger than in New Bedford, but even then it is probably less than double the quantity used for domestic purposes in that city. In the outlying districts with large lawns and gardens the consumption of water is higher, as shown by the amount used in Brookline, Newton, Needham and Wellesley in the diagram already exhibited. While the amount of manufacturing in these towns is comparatively small, yet with nearly 100 per cent of the services metered they are using over 80 gal. per capita. The use for manufacturing in the Metropolitan Water District is probably less per inhabitant than in the case of New Bedford.

It will be noted that the consumption of water per capita in the city of Boston is much higher then in any other cities and towns of the Metropolitan District and that the percentage of metered services is less than in the district outside the city. The per capita consumption in Boston rose to 152.4 gal. in 1907 before the general use of meters, and dropped to 104.2 gal. in 1915 after about 53 per cent of the services had been metered. Since that time the amount used has increased, amounting to 126 gal. in 1920. It is possible that a considerable reduction may be effected in the consumption of water in the city of Boston by the application of meters to the remaining services, though this seems hardly probable. It is natural that the consumption of water per capita in the city of Boston should be considerably higher than in the Metropolitan District as a whole, because the city contains the principal business center of the entire district and is peopled during the day by many thousands who live in other parts of the district or outside its borders. No doubt a very large quantity of water is consumed in the down-town section of the city by those who live in other places, thus greatly increasing the consumption of water per capita charged to Boston. Some indication of the increase in population of the city of Boston in the day time is furnished by records of passengers carried by the railroads, the subways, elevated and trolley lines, and from these records it is possible to estimate probably quite closely the population which is to be provided for in addition to that of the city itself. From a study of these records it appears probable that the population of the city of Boston is increased during the day time by some 250 000 people or more, who live outside its limits. When the fact is taken into account that the population is increased one-third during the day time, it is important that allowance for this increase be made in estimating the degree to which the consumption of water in the city can be reduced. In view of the fact that the consumption has begun to increase since 62 per cent of the services were metered, there is no great encouragement to expect that a further material reduction in the consumption of water per capita will be effected by metering the remaining services.

Possibility of Reducing the Consumption of Water by the Use of Auxiliary Supplies for Manufacturing.

This question has always arisen in connection with investigations for an additional water supply. The only large sources of supply of fresh water are the rivers which flow through the district, especially the Charles, the Mystic and the Neponset rivers, which carry considerable volumes of water, especially in the winter and spring. A large part of the flow of the Charles River is withdrawn before it reaches the Metropolitan Water District in the drier part of the year, and very little water is available except in the Charles River Basin. The water of the basin might possibly be used for some manufacturing purposes during a considerable part of the year, especially towards its upper end, but during much of the time the water of the basin is largely salt, and this is especially true in dry years. It is not probable that any considerable permanent supply of water for manufacturing can be obtained from that source. The water of the Neponset River and of the Mystic River within the limits of the Metropolitan District are far too badly polluted for most manufacturing purposes. There are large numbers of wells within the limits of the Metropolitan District and in some sections where conditions are favorable for the purpose considerable quantities of ground water are obtained, but the areas in which water can be obtained from the ground in considerable quantities are quite limited and the aggregate amount of water obtainable in this way for manufacturing is probably insignificant as compared with the amount used from the public works. There is little to expect in the way of increased water supply from the further development of local sources for industrial uses.

Prevention of Losses by Leakage.

The prevention of loss of water by leakage from distribution pipes is receiving much attention especially by the Boston Water Department, and excellent results have been obtained during the comparatively short time this work has been in progress, a considerable saving in the loss of water having already been effected. The results of this work so far as it has been carried indicate, however, that the preventable loss of water is not great in comparison with the whole amount of water used and such loss is likely to persist and to be more or less constant even with the most efficient inspection practicable. This is true especially in some of the older parts of the city where the water pipes have been laid for many years in streets in which numerous other structures have been placed, increasing the danger of breaks and leaks. It is probable that most of the loss of water by leakage from water pipes is due to numerous comparatively small leaks which are distributed over so great a length of pipe line that the cost of wholly eliminating them would obviously be prohibitive, but the work of eliminating losses of water by leakage, so far as it is practicable to eliminate them, is of the highest importance in preventing a greater increase in the consump-

tion of water per capita and losses and damage in other ways. While in earlier years, when water mains were sometimes constructed of inferior material or laid without sufficient care, the losses of water by leakage from pipes were in some cases large, it is probable that such installations have been for the most part eliminated and it is doubtful whether there is a material preventable loss of water by leakage from water mains in the Metropolitan Water District as a whole at the present time.

Consumption of Water in the Great Cities of the United States.

It is of interest in considering the probable future use of water in the Metropolitan Water District to compare the consumption per capita with that of other great cities in the United States at the present time. This comparison is shown in the following table, which includes all of the northern cities east of the Rocky Mountains which had a population in 1920 in excess of 400 000. From this table it appears that the consumption of water in the Boston Metropolitan District is less than in any city of over 400 000 inhabitants in the northern part of the United States where the climatic conditions are similar to those at Boston.

Comparison of Consumption of Water per Capita in Metropolitan Water District with Consumption in Northern Cities of the United States where Population is in Excess of 400 000.

	Population.	1920 Per Cap. Cons. (Gallons).	% Metered Services.
New York	5 620 048	131	....
Chicago	2 701 705	253	....
Philadelphia	1 823 779	170	23
Boston Met. Dist.*	1 252 903	104.5	75.6
Detroit	993 678	144	97
Cleveland	796 841	152	100
St. Louis (Mo.)	772 897	135	8
Baltimore	733 826	154	3
Pittsburgh	588 343	236	38
Buffalo	506 775	274	8
Milwaukee	457 147	134	99
Washington	437 571	144	85
Newark	414 524	108	92
Cincinnati	401 247	123	99

* Including Newton.

Variation in the Consumption of Water from Year to Year.

In studying the records of water consumption of the past with a view to applying them in estimating for the future, it is necessary to make allowance for variations due to a variety of causes, among which are the activity of business and industry, meteorological conditions, the efficiency of methods of preventing unnecessary use and waste, besides other circumstances.

Business and industrial conditions have a material effect upon the consumption of water because of its extensive use for mechanical, manufacturing and general industrial purposes. The very low consumption of water between 1893 and 1896 was doubtless largely due to the great business depression in those years. The same is true in 1915 and, while complete returns are not available for 1921, a similar reduction is to be expected in that year. Meteorological conditions — heat, drought, excessive cold or unusual rainfall — also produce very marked variations in the consumption of water from year to year. In very dry periods much more water is used than in years of average rainfall and in periods of great heat the draft upon the water supply system is much larger than usual. Excessive rainfall, on the other hand, if occurring in the warmer part of the year, reduces the draft of water from the public works.

More marked even than great heat or drought is the effect of winter temperatures upon the use of water. In very cold winters the use of water is greatly increased because of the necessary waste to prevent the freezing of pipes. This amounted in a recent cold winter to an average of over 18 million gallons per day during the four winter months.

No doubt a part of the low consumption in 1915, as already stated, was attributable to the poor business conditions in that year, but a large part must also be attributed to the mildness of the winter and to the unusual summer rainfall. In 1921 there was also an extremely mild winter, one of the mildest ever recorded in New England, and a very wet summer. There was also a serious business depression, more severe probably than in 1915, and these conditions should cause a very low consumption of water in 1921.

Another cause of variation in the consumption of water from public works in the past has been that resulting from the varying efficiency of methods adopted for the prevention of waste. In earlier years inspection was relied upon to prevent loss of water in this way, but not until the application of meters to water services generally, furnished a means of preventing unnecessary waste by charging for it at the usual rates, was an adequate method of waste prevention put into effect. That this method has been most effective in preventing excessive use and waste of water is well shown by the decrease in the consumption of water in nearly all cities, including the Metropolitan Water District, following the general introduction of meters. This decrease was no doubt due in part to the fear of large water bills under the meter system, but since experience did not show

that the use of meters caused a materially higher charge to the householder than the former system, provided the plumbing was kept in reasonably satisfactory condition, and since in many cases the charge was less than before the meter was applied, it is probable that after a time less care is exercised in restricting the amount of water used than was the case when the meter was first installed. There are cases also in which after the meter system has been put in operation it has not been maintained with the care and efficiency necessary to the best results and its effectiveness has become materially reduced. These conditions have appeared thus far only in a very few cases, but the fact that they have occurred is an indication that there are likely to be variations in the consumption of water in the future due to the varying efficiency in the maintenance of the meter system and in the efforts made to prevent waste.

The conclusions to be drawn from the experience of the cities in which service pipes are largely or wholly metered shows clearly that, notwithstanding the general use of the meters, there is an increase in the use of water per capita at the present time in practically every city without exception. The continued use of meters can probably be depended upon to prevent such great increases as were experienced before their use was begun and to keep the waste of water within reasonable limits. This increase will vary from causes such as those already indicated, but that it can be wholly prevented in the future by any means which are now available seems improbable.

Summarizing the results of this study, it is found that there has been on the whole a steady increase in the per capita consumption of water ever since a water supply was first introduced into the principal city of the district many years ago. Its causes are:

(1) The introduction of ample supplies of pure, soft water, supplied under ample pressure in any desired part of a dwelling house, store or factory and capable of advantageous use for a great number of purposes.

(2) A gradually improving standard of living accelerated no doubt by the experiences of the war which have led to a demand for better housing, more plumbing fixtures and other aids to comfort and health obtainable through a freer use of water from the public works.

(3) The increasing use of water for manufacturing and mechanical purposes, especially where no large quantities of fresh water are available for such uses except from the public works.

(4) Unpreventable waste from numerous small leaks which could be repaired only at excessive cost and which with ageing pipes and structures will doubtless continue, notwithstanding the fact that a large amount of waste has been and must continue to be eliminated to the fullest practicable extent.

(5) Metering the remaining services after 75 per cent have been metered is unlikely to have any material effect in reducing the consumption of water per capita, while on the contrary the common and well-nigh

universal experience has been that the per capita consumption continues to increase after 75 per cent of the services have been metered, notwithstanding the increase in the number of meters.

(6) The consumption of water per capita in the Metropolitan Water District is not excessive when compared with cities of similar size in this country. On the contrary it is now decidedly less than in any city of similar population and climatic conditions in the United States.

(7) The cost of water is and will continue to be exceedingly small for a very long time to come; in fact the present price for the average family seldom exceeds the cost of the daily newspapers, and the charge for water is not included in the general tax levy. It is a special tax and on account of the fact that some of the water income is diverted in many cities for other municipal uses, the charges for water even now are higher in some places than they need to be if the water revenue was used solely for providing and maintaining a water supply.

(8) Heat, drought, and excessive cold all produce marked variations in the consumption of water and large allowances must be made for variations from such causes. Extremes of temperature and of rainfall such as have occurred in the past will occur again and perhaps in even greater severity.

It is of course impossible to estimate with certainty the quantity of water that will be used per capita in the Metropolitan District in future years; but in the face of the evidence that the use of water has ever been a constantly increasing one and that the indications point to a growing use in the future, it is unreasonable to ignore the available facts, and while every effort must be made to keep the water consumption within reasonable limits, the health of the people should not be placed in jeopardy or the public put even to serious inconvenience because of the assumption that means can and will be found and applied in the immediate future to restrict the growing use of this important necessity. Prudence requires, that — in estimating for the future — allowance shall be made for an increase in the consumption of water per capita to the extent indicated by past experience.

Estimated Increase in Water Supply Requirements in the Metropolitan Water District.

In the cities included in the table already given the increase in the consumption of water per capita in metered cities has ranged as a general rule from 0.85 to 2.50 gal. per person per year and has averaged 1.31 gal. per year if the year 1920 be omitted. If comparison is made of the consumption of water in the cities of Boston, Somerville, Chelsea and Everett in the early 80's, when effective measures were being enforced to prevent unnecessary use and waste of water, with the consumption of water in the same municipalities in 1920, it appears that the consumption has increased at about the same rate.

The record of the use of water in these four cities covering a long period of years is a very interesting one in this connection, and a summary has been made of the available information as to the consumption of water in these cities since a water supply was first introduced into the city of Boston in 1848. The construction of the Mystic works was not begun until 1862, or 14 years after the completion of the Cochituate works designed for the supply of the city of Boston.

The population and consumption of water, so far as the records show, in these four cities is given in the following table:

POPULATION AND WATER CONSUMPTION.

(Boston with annexations, 1849–1872, inc.)

(Boston with annexations with Somerville, Chelsea and Everett, 1873–1920 inc.)

Year.	Population.	Av. Daily Cons. Mil. Gals.	Per Capita Daily Cons. Gals.	Per Cent Services Metered.
1849	132 378	3.6800	27.8	....
1850	136 881	5.8379	42.7	....
1851	141 603	6.8838	48.6	....
1852	146 325	8.1258	55.5	....
1853	151 046	8.5423	56.6	....
1854	155 768	9.9020	63.6	....
1855	160 490	10.3463	64.5	....
1856	163 960	12.0486	73.5	....
1857	167 430	12.7260	76.0	....
1858	170 900	12.8470	75.2	....
1859	174 370	13.1750	75.6	....
1860	177 840	17.2380	96.9	....
1861	180 736	18.1893	100.6	....
1862	183 631	16.6000	90.4	....
1863	186 527	16.2385	87.0	....
1864	189 422	16.6810	88.1	....
1865	192 318	12.6620	65.8	....
1866	194 557	12.2290	62.8	....
1867	227 752	13.5650	59.6	....
1868	231 257	14.7692	63.9	....
1869	246 713	15.0704	61.2	....
1870	250 526	15.0077	59.9	....
1871	258 497	13.9455	54.0	....
1872	266 468	15.0634	56.5	....
1873	364 086	25.6090	70.3	....
1874	376 130	25.7179	68.4	....
1875	388 175	27.0193	69.6	....
1876	393 283	29.0635	73.9	....
1877	398 390	29.0598	72.9	....
1878	403 498	31.7215	78.4	....
1879	408 605	34.5794	84.6	....
1880	413 713	35.8879	86.7	....
1881	421 350	38.2149	90.7	....
1882	428 987	38.5452	89.9	....

Year	Population.	Av. Daily Cons. Mil. Gals.	Per Capita Daily Cons. Gals.	Per Cent Services Metered.
1883	436 624	39.6561	90.8	....
1884	444 261	31.3002	70.4	....
1885	451 898	32.3446	71.6	....
1886	467 040	34.0277	72.8	....
1887	482 181	37.4811	77.7	....
1888	497 323	41.5691	83.6	....
1889	512 464	39.9005	77.8	....
1890	527 606	42.1731	79.9	....
1891	541 876	46.7421	86.3	....
1892	556 146	51.1232	91.9	....
1895	570 417	58.1957	102.0	....
1894	584 687	56.8421	97.2	....
1895	598 957	60.2581	100.6	....
1896	615 354	68.2393	110.9	....
1897	631 751	70.3862	111.4	....
1898	648 149	Records for this period not available.		
1899	664 546			
1900	680 943			
1901	690 965			
1902	700 987			
1903	711 008			
1904	721 030	100.7935	139.8	5.5
1905	731 052	102.5884	140.3	6.8
1906	747 593	103.3884	138.3	7.7
1907	764 134	109.2872	143.0	9.0
1908	780 675	110.9217	142.1	10.0
1909	797 216	105.8716	132.8	16.6
1910	813 757	98.9463	121.6	24.8
1911	830 018	96.7298	116.5	32.7
1912	862 933	102.1083	118.4	39.5
1913	879 768	90.6642	103.1	45.6
1914	896 603	93.6701	104.4	51.2
1915	913 437	88.9594	97.4	56.5
1916	915 641	92.5047	101.0	61.4
1917	917 844	94.9708	103.5	62.9
1918	920 048	108.9342	118.4	63.2
1919	922 251	102.2390	110.8	64.1
1920	924 455	108.2463	117.1	65.9

Note: East Boston supplied from the Mystic works in 1870, 1871 and 1872, but records of the quantity of water so supplied are not available. If the population of East Boston be deducted for these three years the per capita figures will be 66.2, 58.2 and 62.5 respectively.

These results, together with the estimated population and water consumption in the Metropolitan Water District and these four cities, are shown on the diagram No. 14.

It is possible, of course, that the application of meters to the remaining services in the Metropolitan Water District may reduce the consumption of water slightly within the next few years, although there is no indication from past experience that such a result is likely to be attained. It is

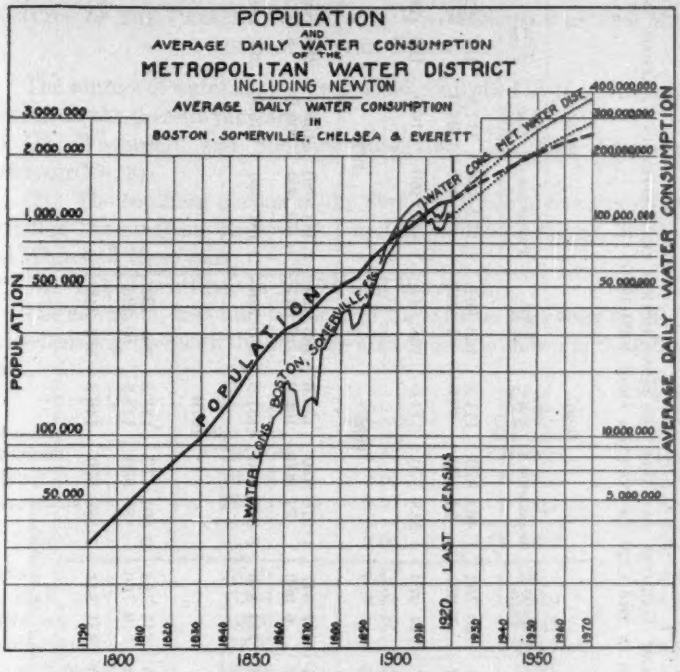


DIAGRAM NO. 14.

probable, however, that some saving can be effected in the loss of water by leakage from pipes. In estimating the future consumption of water per capita in the Metropolitan Water District it has been assumed that the amount of water used will be reduced in the next few years following the year 1920 by the application of meters to unmetered services, and that in consequence of this reduction the consumption will not again rise above 105 gallons until after 1925. Beyond that year it has been estimated that the rate of increase will average about one gallon per capita per year, being slightly greater in the earlier years of the period but growing less as time goes on. Other than the complete metering of all services, including the effective maintenance of the meter system and the prevention of losses of water by leakage so far as it is practicable to prevent them, no further means appear to be available for reducing materially the consumption of water per capita at the present time unless by some form of rationing water which under present conditions would doubtless be deemed impracticable and objectionable. On the basis of this estimate and using the estimates of population already given, the quantity of water required for the supply of the Metropolitan Water District for the next 50 years would be about as shown in the following table:

TABLE SHOWING POPULATION, WATER CONSUMPTION IN THOUSAND GALLONS PER DAY AND CONSUMPTION PER CAPITA IN GALLONS IN METROPOLITAN WATER DISTRICT AND IN THE CITY OF NEWTON FROM 1920–1970.

	1920*			1925			1930			1935		
	Population.	Per Cap. Cons.	Total Cons.	Population.	Per Cap. Cons.	Total Cons.	Population.	Per Cap. Cons.	Total Cons.	Population.	Per Cap. Cons.	Total Cons.
Met. Dist.	1 206 849	105.5	127 265	1 333 680	105.5	140 703	1 463 870	111.8	163 661	1 592 460	117.8	187 592
Newton	46 054	80.1	3 687	50 200	85.0	4 267	54 500	89.6	4 883	58 900	94.0	5 537
TOTAL ...	1 252 903	104.5	130 952	1 383 880	104.7	144 970	1 518 370	111.0	168 544	1 651 360	116.9	193 129

	1940			1945			1950			1955		
Met. Dist.	1 721 550	123.4	212 439	1 851 730	128.5	237 947	1 979 870	132.9	263 125	2 111 080	136.8	288 796
Newton	63 200	98.2	6 206	67 600	102.2	6 909	71 800	106.0	7 611	76 000	109.5	8 322
TOTAL ...	1 784 750	122.5	218 645	1 919 330	127.6	244 856	2 051 670	131.9	270 736	2 187 080	135.8	297 118

	1960			1965			1970		
Met. Dist.	2 241 270	140.5	314 898	2 373 500	144.0	341 784	2 501 170	147.3	368 422
Newton	80 300	112.5	9 034	84 500	115.5	9 760	88 800	118.5	10 523
TOTAL ...	2 321 570	139.5	323 932	2 458 000	143.0	351 544	2 589 970	146.3	378 945

* 1920 figures actual; others estimated.

Capacity of the Present Sources of Water Supply of the Metropolitan Water District.

The sources of water supply owned and controlled by the Metropolitan District at the present time are:

(1) Wachusett and Sudbury Reservoirs, including Framingham Reservoir No. 3;

(2) The southern portion of the Sudbury River above Framingham, including Framingham Reservoirs 1 and 2, and the Ashland, Hopkinton and Whitehall Reservoirs;

(3) Lake Cochituate in Natick and Wayland.

The elevation, area and capacity of the various reservoirs on all these watersheds together with the drainage area of each is shown in the following table:

Reservoir.	Elevation* of High Water.	Area of Reservoir Sq. Mi.	Total Storage Capacity Mil. Gals.	Area of Watershed including Reservoir Sq. Mi.
Wachusett	395.00**	6.46	64 968.0	108.84†
Sudbury	260.00	2.21	7 253.5	22.28
Framingham No. 3	186.74	0.39	1 199.7	5.40
Total		9.06	73 421.2	136.52
Ashland	225.21	0.27	1 416.4	6.43
Whitehall	337.91	0.94	1 256.9	4.35
Hopkinton	305.00	0.30	1 520.9	5.86
Framingham No. 2	177.87	0.21	529.9	28.50
Framingham No. 1	169.32	0.23	289.9	1.84
Cochituate	144.36	1.14	2 097.1	17.58
Farm Pond	159.25	0.26	167.5	0.54
Total		3.35	7 278.6	65.10

Since the Metropolitan water works was established and water first used from the Nashua River on January 1, 1898, the water supply of the district has been obtained very largely from the Wachusett Reservoir, Sudbury Reservoir and Framingham Reservoir No. 3 though at times large quantities of water have been drawn from the other sources; as, for example, in the very dry year of 1911 about 40 per cent of the water used in the Metropolitan Water District was drawn from the Sudbury and Cochituate sources. The quantity of water used from the Wachusett and North Sudbury sources in 1920 was equal to and in fact probably somewhat in excess of their safe capacity in a period of very dry years. Consequently as the consumption of water increases hereafter it will be necessary to draw more and more water from the Cochituate and southern Sudbury sources.

Lake Cochituate furnishes water of very poor quality which, though not very highly colored, contains much organic matter and is usually affected by

* Elevation in feet above Boston City Base.

** It is possible, by use of two flashboards, to raise the water to elevation 397. At that elevation the capacity of the reservoir would be 67 686.1 million gallons.

† Exclusive of areas diverted by the city of Worcester amounting to 9.35 square miles.

an objectionable taste and odor. The water of the southern Sudbury sources is for the most part highly colored and is also affected by tastes and odors. Both the southern Sudbury and Cochituate watersheds, especially the latter, contain large populations per square mile, but while the pollution of Lake Cochituate enters largely at its extreme southerly end the water is drawn from the northerly basin of the lake. The conditions in the southern Sudbury watershed are quite different. The large reservoirs on the Sudbury River are located near the head of the watershed while at the lower end is only the small Framingham Reservoir No. 2, having a total capacity of about 530 000 000 gal. fed by a direct watershed of 28.5 sq. mi. Neither source should be used regularly for the water supply of the district unless properly filtered.

In the case of the Wachusett and Sudbury Reservoirs and Reservoir No. 3, there is also more or less population on the watersheds, especially on that of the Sudbury Reservoir; but most of the sewage is diverted from the watershed of the latter source and all of the water flowing from the densely populated portion of the city is either filtered or treated with chlorine. Long storage is also depended upon both for protection of the supply from the effects of possible pollution and for the improvement of the quality of the water which long storage affords. It has accordingly been assumed in estimating the safe capacity of the Metropolitan sources that enough water will be retained in the Wachusett and Sudbury Reservoirs and in Reservoir No. 3 to secure efficient purification by storage and render the water safe and acceptable for use; and that the water of the southern Sudbury and Cochituate sources will be purified by filtration whenever it becomes necessary to use them again for the supply of the district. For these reasons, in estimating the combined yield of the various watersheds allowance has been made for retaining in Wachusett Reservoir, Sudbury Reservoir and in Reservoir No. 3 a total of something over 20 000 000 000 gal., and in the other reservoirs of the southern Sudbury and Cochituate system about 1 400 000 000 gal., a large part of which would remain in Lake Cochituate and should be retained there to prevent objectionable odors from the exposed bottom of the lake. These allowances especially in the case of the Wachusett Reservoir are less than desirable and if the water were drawn to so low a level the color would probably increase so as to become noticeable in the water supplied to the district.

The estimated gross yield of all the present sources of water supply of the district as given in the State Board of Health report in 1895 was 173 000 000 gal. per day. Since that time water from a part of the Wachusett watershed has been diverted for the use of the city of Worcester and the area of the Wachusett watershed reduced from 118.19 sq. mi. to 108.84 sq. mi. Not all of this water has yet been diverted but when the Pine Hill Reservoir of the city of Worcester, now under construction, is completed, it will be practicable for that city to divert the entire flow of water from the area set apart for its use in dry periods and it is consequently

essential in estimating the safe yield of the Metropolitan water works to assume that all of the water from this area will be diverted by Worcester. Allowing for this diversion the gross yield of the present source is about 169 000 000 gal. per day. The yield is of course larger than the yield of the Sudbury, Cochituate and Wachusett sources computed separately since by operating them together a larger amount can be obtained than by operating them as separate units.

Of the gross yield of 169 000 000 gal., a considerable part is diverted for various purposes, a part is lost by leakage, a further part is used for the water supply of certain cities and towns within the Metropolitan watersheds which are authorized to take water therefrom, another part is lost by leakage into sewerage systems in these watersheds by which it is diverted to points outside their limits, and there are unavoidable losses in other ways. Without going into details, these allowances aggregate about 14 500 000 gal., so that the available safe yield of all existing sources is about 154 500 000 gal. per day. This estimate has been based upon the yield in the dry period from 1908 to 1915, and no allowance has been made for a period of lower rainfall. Such dry periods have occurred some 5 or 6 times in a century, so far as rainfall records in New England show, and in some of these periods there has been a smaller precipitation, and hence no doubt a smaller yield of watersheds than in the dry period which began in 1908. It is to be noted, however, that the estimate is based on the assumption that all of the sources of water supply are available for use at all times. Under present conditions it is unsafe to use the southern Sudbury or Cochituate sources without filtration, and no provision has yet been made for treating these waters. Unless these sources are in regular use, the yield is likely to be less, and perhaps considerably less than the estimate here given.

Consumption of Water in the City of Newton.

In comparing the consumption of water in the Metropolitan Water District with the capacity of the sources, it is essential to consider the city of Newton which, though a part of the district, has continued to supply itself with water, except in emergencies, from its own sources near the Charles River, up to the present time. The capacity of these sources has recently been the subject of a careful study by the city engineer of Newton, which indicates that that city can furnish from its own works at the present time in a very dry period, if these works are used in connection with the Metropolitan Water District, about 4 000 000 gal. of water per day. Without going into details as to the capacity and probable limitations of the yield of the Newton water works sources, it may be said that the estimate of a safe yield of 4 000 000 gal. per day from the Newton sources used in connection with the sources of the Metropolitan Water District, as seems probable, appears to be a reasonable one under the conditions which exist in the Charles River valley at the present time.

Capacity of Present Sources of the Metropolitan Water District to Meet the Requirements of the District.

The estimated yield of all the sources of supply available to the Metropolitan Water District is in round numbers 154 000 000 gal. Adding to this the estimated safe yield of the sources of water supply of the city of Newton, the safe yield of all available sources of the cities and town in the district is 158 000 000 gal. per day. This amount will diminish no doubt in the future on account of increases in the amounts of water diverted for water supply by the towns now using water from the Metropolitan watersheds and also by leakage into the sewerage systems in those watersheds. The following table shows a comparison of the yield of the available sources with the estimated quantity of water required as given in the earlier portion of this report.

Table showing a Comparison of the Yield of the Metropolitan Water Supply Sources Plus those of the City of Newton and the Consumption of Water in the present Metropolitan Water District in Census Years, 1920 to 1935.

	1920*	1925	1930	1935
		(Million Gals. per Day.)		
Safe Yield of all Metropolitan sources including Newton supply	158.0	158.0	158.0	157.0**
Consumption of water in Metropolitan Water District (including Newton)	131.0	145.0	168.5	193.1
Excess	27.0	13.0	....	....
Deficiency	....	....	10.5	36.1

* Actual; other figures estimated.

** An allowance for a reduction of 1 000 000 gallons per day is made to provide for additional increases in the diversions of water from the Metropolitan watersheds and increasing losses by leakage.

This table shows that by the year 1930 the quantity of water required by the district on the basis of the estimates already given will exceed the safe yield of the sources of supply on an average about 10 000 000 gal. per day.

In this estimate no allowance is made for the taking of additional water from the district sources by any of the municipalities having rights reserved therein under various legislative grants which have not yet exercised such right. Rights have been reserved to some 19 municipalities but have thus far been exercised by only 9.

More important still, however, is the fact that no allowance is made in these calculations for supplying water to municipalities outside of the limits of the present district but within the 10-mile radius from the State House which may join the district if they so elect. There are also several other municipalities which may desire to take water from the district and which may properly be supplied therefrom under the terms of the

Metropolitan water act. While neither Worcester nor the other municipalities outside the present limits of the Metropolitan Water District are members of that district, they nevertheless have substantial claims upon a water supply from or in connection with the district, and it is essential that their possible requirements shall be taken into account in any consideration of the future water supply of the Metropolitan Water District. It is not practicable, however, within the limits of this paper to consider except in the briefest way the possible needs and requirements of the municipalities not now connected with the Metropolitan Water District but which are likely to require a water supply from the district in some future time.

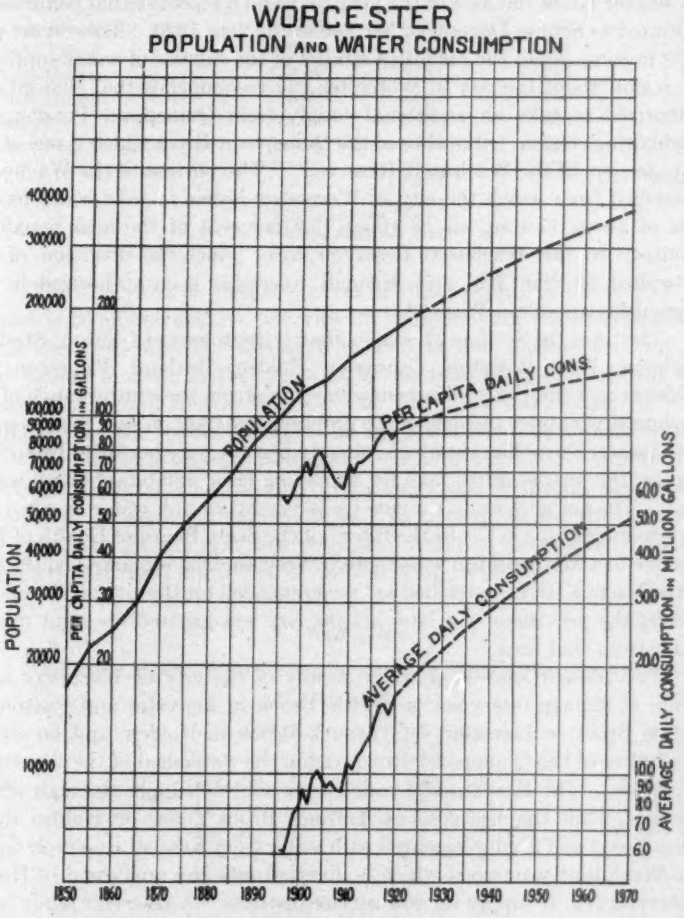


Diagram No. 15.

Water Supply of the City of Worcester.

First in importance among the municipalities requiring consideration in this connection is the city of Worcester which has grown steadily for many years and in which the per capita consumption of water has been increasing quite rapidly in spite of the fact that more than 90 per cent of the services have been metered for the past 26 years. These results, together with the estimated population and water consumption are shown in diagram No. 15.

An investigation for an additional water supply for the city of Worcester was made by a special commission of that city under the authority of Chapter 176 of the Acts of the year 1918 and a report of that commission is printed as Senate Document No. 346 of the year 1920. This report presents in some detail the results of studies of the sources of water supply in the region about the city of Worcester and recommends that that city be authorized to take an additional supply from Quinepoxet Pond and a neighboring stream, tributaries of the Quinepoxet River which is one of the main feeders of the Wachusett Reservoir. The portion of the Wachusett watershed from which the city of Worcester desires to take water has an area of about 17.4 sq. mi. or about 15.9 per cent of the area remaining tributary to the Wachusett Reservoir, after which the diversion of the watershed of Pine Hill and Kendall reservoirs was authorized in the original Metropolitan Water Act.

That Act, in Section 22, states that " the towns of Clinton, Sterling, Boylston, West Boylston, Lancaster, Holden, Rutland, Princeton and Leicester and the city of Worcester may take from the south branch of the Nashua River above the dam of the proposed reservoir on said river so much of the water thereof as they have already been or may hereafter be authorized by the legislature to take for supplying their inhabitants with water, etc." The act goes on to provide for payment for any water that may be diverted under the act. In the report of the State Board of Health of 1895 relative to a Metropolitan water supply a certain area is marked on the plan of the Nashua River watershed as "recommended for the city of Worcester" and by the provisions of a later act the city was granted the right to take water from that area.

The present sources of water supply of the city of Worcester are a group of storage reservoirs on Kettle Brook in Leicester and Paxton, on Lynde Brook in Leicester, on Tatnuck Brook in Holden, and on certain tributaries of the Quinepoxet River within the watershed of the Wachusett Reservoir. The Kettle and Lynde Brook sources supply the high service districts, while the reservoirs on Tatnuck Brook known as Holden Reservoirs Nos. 1 and 2, supplemented with water from Kendall Reservoir within the Wachusett watershed which is diverted into the upper end of Holden Reservoir No. 1, supply the low service districts. A reservoir much larger than any now in use, known as the Pine Hill Reservoir, is being constructed

within the portion of the Wachusett watershed assigned to Worcester. The water of this reservoir will flow by gravity to Kendall Reservoir and thence to the Holden Reservoirs.

The area and capacity of the various reservoirs are given in the following table.

WORCESTER

Reservoir.	Elevation.** (Feet)	Area of Reservoir (Sq. Mi.)	Total Storage Capacity (Mil. Gals.)	Area of Watershed including Reservoir (Sq. Mi.)
Kettle Brook, No. 4	1 082.74	0.186	514	1.805
Kettle Brook, No. 3	1 040.00	0.058	152	0.722
Kettle Brook, No. 2	988.50	0.048	127	0.569
Kettle Brook, No. 1	845.36	0.007	19	1.002*
Lynde Brook	822.94	0.206	701	2.921
Upper Holden	750.88	0.211	794	4.555
Lower Holden	718.80	0.089	283	0.676
Kendall	814.00	0.273	850	2.451
Pine Hill	910.00	0.720	3 000	6.899
		1.798		21.600

* Includes Peter Brook.
** Above Mean Sea Level.

The safe yield of present sources of water supply of the city of Worcester is 16 million gallons, but with the completion of the Pine Hill Reservoir the yield will be increased to 19.3 million gallons per day. At the rate of increase in the use of water maintained by the city for many years, the present sources with the Pine Hill Reservoir completed will be sufficient for the requirements of the city for about 5 or 6 years only.

The city of Worcester now desires an additional water supply. It is probable, however, that the city of Worcester will eventually supply water to some of the adjacent municipalities. Its population and the quantity of water used by the city in census years since 1900 and the estimated quantity required until 1970 are shown in the following table.

WORCESTER

POPULATION, DAILY WATER CONSUMPTION AND PER CAPITA CONSUMPTION, 1900–1920.

Year.	Population.	Per Capita Consumption (Gals.).	Total Consumption (Gals.).
1900	118 421	69.0	8 153 000
1905	128 135	75.0	9 581 000
1910	145 986	74.0	10 805 000
1915	162 697	79.0	12 818 000
1920	179 754	91.9	16 515 000

ESTIMATED POPULATION, DAILY WATER CONSUMPTION AND PER CAPITA CONSUMPTION 1920–1970.

	Population.	Per Capita Consumption (Gals.).	Total Consumption (Gals.).
1920*	179 754	91.9	16 515 000
1925	198 500	96.8	19 215 000
1930	217 500	101.6	22 098 000
1935	237 000	106.2	25 169 000
1940	257 100	111.0	28 538 000
1945	277 800	115.5	32 086 000
1950	298 000	120.1	35 790 000
1955	318 800	124.3	39 627 000
1960	339 600	128.6	43 673 000
1865	360 000	132.8	47 808 000
1970	380 700	137.0	52 156 000

* 1920 figures actual; others estimated.

PROBABLE REQUIREMENTS OF CITIES AND TOWNS WITHIN 10 MILES OF THE STATE HOUSE NOT AT PRESENT INCLUDED IN THE METROPOLITAN WATER DISTRICT.

The cities and towns within the 10-mile limit from the State House which are eligible to join the Metropolitan Water District under the provisions of the Metropolitan Water Act are the following:

Cambridge	Canton	Hull	Saugus
Brookline	Braintree	Wakefield	Winchester
Wellesley	Weymouth	Woburn	Waltham
Needham	Hingham	Lynn	Dedham

The Metropolitan Water Act, Chapter 488 of the Acts of the year 1895, provides that the Metropolitan Water Board "shall on application admit any other city or town, any part of which is within ten miles of the State House, into said water district, etc. . . . on such payment of money as said board may determine." As already stated a number of cities and towns have joined the District since the Metropolitan Water Act was passed and it is interesting to examine the conditions under which those municipalities were admitted to the district and the entrance fee paid for the purpose.

The towns which have been admitted since the district was created and the amounts paid by each are as follows:

Arlington, admitted Jan. 31, 1899, entrance fee $15 000 and property valued at $15 000.

Lexington, admitted Feb. 13, 1903, entrance fee $27 250.

Milton, admitted March 10, 1903, entrance fee $10. (Previous payments by Milton Water Company being a consideration in part for admittance.)

Nahant, admitted Sept. 13, 1898, entrance fee $20 000 and an annual payment of $800 until Swampscott began to buy water.

Quincy, admitted June 24, 1897, entrance fee $5 000.

Stoneham, admitted May 23, 1901, entrance fee $30 000.

Swampscott, admitted May 3, 1909, entrance fee $90 000.

It will be seen from this record that the last town admitted was Swampscott in 1909, 13 years ago, and the last one previous to Swampscott was Milton admitted in 1903, 19 years ago. A number of cities and towns have since sought to join the district but have been deterred mainly by the large entrance fee likely to be assessed upon them for admission.

This question of the charge for the admission of other cities and towns to the Metropolitan Water District is constantly arising. Hitherto it has been customary to require the municipality applying for entrance to the district to pay its proportionate share of the accumulated sinking fund as determined by the Commission, with possibly some extra charge for the necessary works required for a physical connection with the District. The method was a satisfactory one in the beginning at least, because for those who came in early the share of the sinking fund was comparatively small, and at that time the works were ample for all requirements.

In the year of the last admission, in 1909, the sinking fund amounted to $7 203 406.08. With the increase in the total amount of the sinking fund which amounted in 1920 to $16 953 165.15 the charge for admission of additional municipalities has been necessarily a constantly increasing one; yet, while the charge for admission is increasing, the prospective benefit of the works to the entering municipality, as well as their practical value, is decreasing, since their capacity is being approached and some obsolescence has occurred.

The matter has reached a stage where the cost of admission has apparently become a serious deterrent to the addition of other municipalities to the Metropolitan Water District. In the end of course, within a comparatively few years, the sinking fund will be used for the payment of the bonds, the debt will be fully paid, and the basis for this method of determining the charge for admission of other municipalities to the district will disappear. With the increase in the size of the works which must inevitably be made and the material addition to the cost which must come in the immediate future, it seems necessary that a new basis for the charge for entrance to the district should be devised.

The Metropolitan water act gives the Metropolitan District Commission the sole right to determine the charges for admission of other cities and towns to the Metropolitan Water District; but a change in the law could probably be made if agreed to by the Metropolitan District Commission, and an arrangement might be reached which would be a reasonable one and would be generally acceptable. The charge based on the past methods of computation are regarded, probably with reason, as excessive at the present time. The method should be revised as promptly as possible in the interests of all concerned. The matter is a most important one and its present status unsatisfactory.

The aggregate population in 1920 of the sixteen municipalities which though eligible have not joined the district, was 391 448; and the total quantity of water consumed by them was 34 241 000 gal. per day, or 87.4 gal. per person per day. The population, per capita consumption, per cent of metered services and total consumption of water in each of these municipalities, so far as the records are available in the last 20 years, are shown in the following table.

POPULATION AND CONSUMPTION OF WATER OF 16 MUNICIPALITIES WITHIN 10 MILES OF STATE HOUSE.

1900–1920.

	1900			1901		
	Population.	Per Capita Consumption. (Gals.)	Total Consumption. (1000 Gals.)	Population.	Per Capita Consumption. (Gals.)	Total Consumption. (1000 Gals.)
Cambridge	91 886	79.0	7 304	92 996	83.0	7 690
Brookline	19 935	97.0	1 941	20 635	92.0	1 902
Wellesley	5 072	47.0	239	5 295	46.0	244
Needham	4 016	56.0	224	4 070	57.0	231
Canton*	4 584	46.0	209	4 608	43.0	197
Braintree	5 981	91.0	544	6 161	78.0	479
Weymouth**	11 324	.....	610	11 376	.....	630
Hingham†	5 059	50.8	257	5 011	51.5	258
Hull†	1 703	145.0	247	1 774	146.8	260
Wakefield(e)	9 290	60.0	557	9 500	60.0	570
Woburn	14 254	78.0	1 117	14 284	78.0	1 120
Lynn Saugus	73 597	64.0	4 680	75 537	60.0	4 506
Winchester(f)	7 248	.....	225	7 447	.....	240
Waltham	23 481	90.0	2 118	24 041	95.0	2 291
Dedham	7 457	79.0	586	7 520	83.0	621
TOTALS	284 887	73.2	20 858	290 255	73.2	21 239

	1902			1903		
Cambridge	94 105	86.0	8 099	95 215	91.0	8 642
Brookline	21 335	92.0	1 961	22 036	96.0	2 116
Wellesley	5 519	47.0	257	5 742	51.0	294
Needham	4 123	67.0	275	4 177	71.0	295
Canton	4 631	49.0	226	4 655	55.0	254
Braintree	6 340	85.0	538	6 520	88.0	574
Weymouth	11 428	.....	650	11 481	.....	670
Hingham	4 963	52.2	259	4 915	52.8	260
Hull	1 846	148.5	274	1 917	150.2	288
Wakefield	9 681	60.0	577	9 877	60.0	588
Woburn	14 313	83.0	1 193	14 343	94.0	1 351
Lynn Saugus	77 476	60.0	4 684	79 416	65.0	5 138
Winchester	7 646	.....	250	7 844	.....	255
Waltham	24 601	99.0	2 435	25 162	90.0	2 254
Dedham	7 584	89.0	675	7 647	104.0	796
TOTALS	295 591	75.6	22 353	300 947	79.0	23 775

For references, see page 230.

	1904			1905		
	Population.	Per Capita Consumption. (Gals.)	Total Consumption. (1000 Gals.)	Population.	Per Capita Consumption. (Gals.)	Total Consumption. (1000 Gals.)
Cambridge	96 324	92.0	8 847	97 434	92.0	8 973
Brookline	22 736	103.0	2 348	23 436	95.0	2 228
Wellesley	5 966	52.0	313	6 189	47.0	289
Needham	4 230	65.0	274	4 284	66.0	284
Canton	4 678	62.0	288	4 702	63.0	296
Braintree	6 699	88.0	592	6 879	87.0	600
Weymouth	11 533	.....	690	11 585	.....	700
Hingham	4 867	53.5	260	4 819	54.1	261
Hull	1 989	152.0	302	2 060	153.8	317
Wakefield	10 072	65.0	655	10 268	73.0	747
Woburn	14 372	98.0	1 413	14 402	103.0	1 490
Lynn Saugus	81 355	66.0	5 333	83 295	59.0	4 924
Winchester	8 043	.....	260	8 242	.....	270
Waltham	25 722	81.0	2 073	26 282	79.0	2 070
Dedham	7 711	135.0	1 041	7 774	135.0	1 046
TOTALS	306 297	80.6	24 689	311 651	78.6	24 495

	1906			1907		
Cambridge	98 915	96.0	9 491	100 396	109.0	10 992
Brookline	24 307	84.0	2 048	25 178	89.0	2 236
Wellesley	6 034	45.0	273	5 879	52.0	305
Needham	4 432	77.0	342	4 581	69.0	315
Canton	4 721	49.0	230	4 740	51.0	244
Braintree	7 116	77.0	549	7 354	66.0	484
Weymouth	11 848	.....	720	12 109	.....	740
Hingham	4 848	54.7	265	4 877	55.4	270
Hull	2 069	155.5	322	2 077	157.2	327
Wakefield	10 495	69.0	729	10 722	68.0	724
Woburn	14 583	104.0	1 513	14 764	114.0	1 682
Lynn Saugus	86 113	60.0	5 133	88 930	68.0	6 018
Winchester	8 455	.....	280	8 669	.....	290
Waltham	26 592	73.0	1 941	26 903	84.0	2 272
Dedham	8 076	95.0	770	8 378	104.0	868
TOTALS	318 604	77.2	24 606	325 557	85.3	27 767

	1908			1909		
Cambridge	101 877	103.0	10 450	103 358	95.0	9 859
Brookline	26 050	90.0	2 353	26 921	86.0	2 314
Wellesley	5 723	54.0	310	5 568	58.0	324
Needham	4 729	75.0	355	4 878	69.0	335
Canton	4 759	59.0	280	4 778	60.0	287
Braintree	7 591	56.0	424	7 829	63.0	493
Weymouth	12 371	.....	770	12 633	.....	790
Hingham	4 907	56.0	275	4 936	56.7	280
Hull	2 086	159.0	332	2 094	160.8	337
Wakefield	10 950	67.0	730	11 177	62.0	698
Woburn	14 946	111.0	1 652	15 127	119.0	1 803
Lynn Saugus	91 748	67.0	6 118	94 565	68.0	6 394
Winchester	8 882	.....	300	9 095	.....	310
Waltham	27 213	83.0	2 266	27 524	87.0	2 382
Dedham	8 680	109.0	947	8 982	129.0	1 160
TOTALS	332 512	82.9	27 562	339 465	81.8	27 766

	1910			1911		
	Population.	Per Capita Consumption. (Gals.)	Total Consumption. (1000 Gals.)	Population.	Per Capita Consumption. (Gals.)	Total Consumption. (1000 Gals.)
Cambridge	104 839	100.0	10 458	105 636	97.0	10 226
Brookline	27 792	89.0	2 476	28 932	90.0	2 605
Wellesley	5 413	61.0	331	5 618	63.0	354
Needham	5 026	66.0	332	5 329	58.0	308
Canton	4 797	61.0	293	4 962	65.0	323
Braintree	8 066	81.0	653	8 321	63.0	524
Weymouth	12 895	.....	810	13 110	.....	840
Hingham	4 965	57.3	284	5 025	57.9	291
Hull	2 103	162.5	342	2 140	164.2	351
Wakefield	11 404	61.0	694	11 679	57.0	664
Woburn	15 308	139.0	2 134	15 528	120.0	1 856
Lynn, Saugus	97 383	72.0	7 027	99 112	68.0	6 710
Winchester	9 309	.....	325	9 448	.....	340
Waltham	27 834	88.0	2 443	28 298	89.0	2 513
Dedham	9 284	129.0	1 202	9 636	128.0	1 235
TOTALS	346 418	86.0	29 804	352 774	82.6	29 140

	1912			1913		
Cambridge	106 432	101.0	10 793	107 229	98.0	10 549
Brookline	30 071	88.0	2 633	31 211	87.0	2 708
Wellesley	5 823	64.0	374	6 029	65.0	389
Needham	5 632	63.0	356	5 936	58.0	344
Canton	5 127	75.0	386	5 293	64.0	338
Braintree	8 577	68.0	587	8 832	62.0	545
Weymouth	13 325	.....	870	13 539	.....	900
Hingham	5 085	58.6	298	5 144	59.2	304
Hull	2 178	166.0	362	2 215	167.8	372
Wakefield	11 955	60.0	713	12 230	56.0	684
Woburn	15 749	128.0	2 014	15 969	109.0	1 744
Lynn, Saugus	100 841	67.0	6 750	102 571	62.0	6 366
Winchester	9 587	.....	350	9 727	.....	360
Waltham	28 762	95.0	2 743	29 226	93.0	2 714
Dedham	9 988	116.0	1 156	10 339	108.0	1 121
TOTALS	359 132	84.6	30 385	365 490	80.6	29 438

	1914			1915		
Cambridge	108 025	94.0	10 137	108 822	82.0	8 957
Brookline	32 350	89.0	2 875	33 490	82.0	2 750
Wellesley	6 234	64.0	398	6 439	73.0	470
Needham	6 239	63.0	395	6 542	62.0	405
Canton	5 458	53.0	291	5 623	56.0	313
Braintree	9 088	60.0	549	9 343	53.0	498
Weymouth	13 753	.....	930	13 969	69.0	966
Hingham	5 204	59.9	312	5 264	60.5	318
Hull	2 253	169.5	382	2 290	171.2	392
Wakefield	12 506	47.0	590	12 781	46.0	592
Woburn	16 190	116.0	1 883	16 410	122.0	1 996
Lynn, Saugus	104 300	65.0	6 761	106 029	60.0	6 385
Winchester	9 866	.....	380	10 005	.....	395
Waltham	29 690	83.0	2 465	30 154	76.0	2 294
Dedham	10 691	99.0	1 054	11 043	88.0	973
TOTALS	371 847	79.1	29 402	378 204	73.3	27 704

	1916			1917		
	Population.	Per Capita Consumption. (Gals.)	Total Consumption. (1000 Gals.)	Population.	Per Capita Consumption. (Gals.)	Total Consumption. (1000 Gals.)
Cambridge	108 993	89.0	9 711	109 171	89.0	9 712
Brookline	34 342	83.0	2 838	35 193	87.0	3 078
Wellesley	6 396	78.0	498	6 353	86.0	544
Needham	6 636	62.0	413	6 730	56.0	379
Canton	5 687	53.0	301	5 752	51.0	296
Braintree	9 590	65.0	625	9 838	60.0	588
Weymouth	14 187	65.0	918	14 404	78.0	1 127
Hingham	5 332	61.1	326	5 400	61.8	334
Hull	2 186	173.0	378	2 082	174.8	364
Wakefield	12 830	48.0	619	12 879	43.0	554
Woburn	16 443	136.0	2 229	16 476	124.0	2 046
Lynn Saugus	106 828	66.0	7 065	107 626	68.0	7 316
Winchester	10 101	.....	410	10 197	.....	430
Waltham	30 306	75.0	2 258	30 458	74.0	2 249
Dedham	10 993	92.0	1 008	10 943	95.0	1 041
Totals	380 853	77.7	29 597	383 502	78.4	30 058

	1918			1919		
Cambridge	109 345	102.0	11 127	109 520	96.0	10 513
Brookline	36 045	87.0	3 144	36 896	90.0	3 309
Wellesley	6 310	86.0	545	6 267	83.0	522
Needham	6 824	68.0	462	6 918	57.0	396
Canton	5 816	68.0	393	5 881	75.0	439
Braintree	10 085	72.0	722	10 333	62.0	637
Weymouth	14 622	99.0	1 445	14 839	81.0	1 208
Hingham	5 468	62.4	341	5 536	63.1	349
Hull	1 979	176.5	349	1 875	178.2	334
Wakefield	12 927	61.0	786	12 976	45.0	584
Woburn	16 508	141.0	2 320	16 541	109.0	1 796
Lynn Saugus	108 425	77.0	8 374	109 223	74.0	8 048
Winchester	10 293	42.0	435	10 389	43.0	444
Waltham	30 611	82.0	2 510	30 763	63.0	1 952
Dedham	10 892	104.0	1 133	10 842	73.0	796
Totals	386 150	88.3	34 086	388 799	80.6	31 327

	1920		
	Population.	Per Capita Consumption. (Gals.)	Total Consumption. (1000 Gals.)
Cambridge ...	109 694	104.2	11 435
Brookline	37 748	91.4	3 451
Wellesley	6 224	86.1	536
Needham	7 012	64.2	450
Canton	5 945	70.5	419
Braintree	10 580	70.1	742
Weymouth ..	15 057	97.0	1 464
Hingham	5 604	63.7	357
Hull	1 771	180.0	319
Wakefield ...	13 025	47.6	620
Woburn	16 574	127.0	2 104
Lynn ..... Saugus	110 022	82.8	9 113
Winchester ..	10 485	45.0	472
Waltham	30 915	63.4	1 960
Dedham	10 792	74.0	799
TOTALS ..	391 448	87.5	34 241

* Canton — 1913 and 1920 water consumption figures estimated.
** Weymouth — All water consumption figures estimated, except 1915-20, inclusive.
† Hingham and Hull — Water consumption figures estimated.
(*e*) Wakefield — 1900 and 1901 estimated figures for water consumption.
(*f*) Winchester — All water consumption figures estimated, except 1918 and 1919.

Most of these municipalities must inevitably obtain all or part of their water supplies from the Metropolitan Water District in the not distant future, that is within the next 10 or 15 years, though some of them have water enough to last for a longer time. Out of the total population of about 391 000 in these cities and towns in 1920, it is probable that about two-thirds or about 270 000 will require a water supply from the Metropolitan Water District within the next 10 or 15 years, the length of this period depending largely upon the rainfall. These suburban municipalities use less water per capita of course than the present Metropolitan Water District and in estimating future requirements of the district including these municipalities a smaller consumption of water is allowed for than in the case of the district alone.

Besides the municipalities within the 10-mile limit, there are others beyond that limit which may require a water supply from the Metropolitan District within the next 10 to 15 years, some for the reason that their water supplies are limited and are likely soon to become exhausted, others because of the poor quality of the waters now used, and still others because of the expense of maintaining their present works. The more important of these municipalities contained an aggregate population in 1920 of 44 120.

Without going into the matter further and omitting any consideration of the remaining towns which have rights to take water from the Metropolitan watersheds and omitting also those towns which will naturally take their water supplies at some time in the future from the city of Worcester, there is a total population of some 570 000 which, including the city of Worcester, either have rights in the Metropolitan watersheds or may claim the right to a supply of water from the Metropolitan Water District. A number of these places, however, can probably obtain a sufficient quantity of water from their own sources for many years.

It is not practicable within the limits of this paper to give a detailed statement as to the water supplies of all of the cities and towns which may desire to join the Metropolitan Water District or may require a water supply therefrom within the not distant future. With the coming of a dry period there is likely to be a large increase in water supply requirements from the district sources coming from territory outside its present limits, and the demands of outside cities and towns for water for use in emergencies could not of course be denied. It is necessary, however, that all local sources which are still suitable for use shall be continued in use so long as practicable and only surplus requirements drawn from the works of the Metropolitan Water District until the district sources have been materially increased.

Including the city of Worcester and about two-thirds of the population in the municipalities within the 10-mile limit of the State House which are not at present connected with the Metropolitan Water District and omitting any provision for municipalities outside that limit, the total population to be supplied and the quantity of water which is likely to be required for the next 15 years would be about as shown in the following table:

	1920			1925		
	Population.	Per Capita Daily Consumption. (Gals.)	Average Daily Consumption. (Gals.)	Population.	Per Capita Daily Consumption. (Gals.)	Average Daily Consumption. (Gals.)
Metropolitan District as supplied	1 206 849	105.5	127 265 000	1 333 680	105.5	140 703 000
Newton	46 054	.....	3 687 000	50 200	.....	4 267 000
TOTAL	1 252 903	104.5	130 952 000	1 383 880	104.8	144 970 000
Near-by cities and towns	272 840	.....	24 659 000	299 276	.....	28 288 000
TOTAL	1 525 743	102.0	155 611 000	1 683 156	102.9	173 258 000
Worcester	179 754	.....	16 515 000	198 500	.....	19 215 000
TOTAL	1 705 497	100.9	172 126 000	1 881 656	102.3	192 473 000

	1930			1935		
Metropolitan District as supplied	1 463 870	111.8	163 661 000	1 592 460	117.8	187 592 000
Newton	54 500	.....	4 883 000	58 900	.....	5 537 000
TOTAL	1 518 370	111.0	168 544 000	1 651 360	116.9	193 129 000
Near-by cities and towns	327 512	.....	32 249 000	355 358	.....	36 260 000
TOTAL	1 845 882	108.8	200 793 000	2 006 718	114.3	229 389 000
Worcester	217 500	.....	22 098 000	237 000	.....	25 169 000
TOTAL	2 063 382	108.0	222 891 000	2 243 718	113.5	254 558 000

The quantity of water which may be required from the sources of water supply of the Metropolitan District by the population which is likely to take water from the district within the next 15 years, as compared with the capacity of available sources, is shown in the following table:

	Million Gallons per Day.			
	1920	1925	1930	1935
Safe yield of sources of Metropolitan Water District plus Newton	158.0	158.0	158.0	157.0
Safe yield of sources of nearby cities and towns,—which can probably be retained in use	22.8	22.8	22.8	22.8
TOTAL SAFE YIELD	180.8	180.8	180.8	179.8
Requirements of Metropolitan Water District and Newton	131.0	145.0	168.5	193.1
Requirements of nearby cities and towns	24.6	28.3	32.3	36.3
TOTAL REQUIREMENTS	155.6	173.3	200.8	229.4
Excess of safe yield over requirements of District alone	27.0	13.0	.....	.....
Deficiency	.....	.....	10.5	36.1
Excess of safe yield over requirements with adjacent municipalities added	25.2	7.5	.....	.....
Deficiency	.....	.....	20.0	49.6
Safe yield of present sources which can be retained in use, with Worcester added	200.1	200.1	200.1	199.1
Total requirements, with Worcester added	172.1	192.5	222.9	254.6
Excess of safe yield over requirements	28.0	7.6	.....	.....
Deficiency	.....	.....	22.8	55.5

It will be seen from the foregoing table that the consumption of water in the Metropolitan Water District at the probable rate of increase indicated by past experience is likely to exceed the safe capacity of the present sources in the year 1930 by about 10 million gallons per day. If other cities and

towns within the 10-mile radius from the State House should join the district and take only their surplus requirements therefrom beyond the capacity of their present sources, the deficiency in the supply of the Metropolitan District in that year may reach 20 000 000 gal. per day without allowance for the city of Worcester. The requirements of the district alone as at present constituted are likely to reach to from 30 000 000 to 35 000 000 gal. per day in excess of the yield of present sources by 1935 and to over 80 000 000 gal. per day 10 years later. Of course if the city of Worcester and other municipalities should be added to the district or should take water from the District sources, as inevitably will be the case, these amounts would be materially exceeded.

Present Situation of the Metropolitan Water District and Other Municipalities in its Neighborhood in Eastern Massachusetts with Regard to Water Supply.

The seriousness of the situation with regard to water supply in eastern Massachusetts, that is in the Metropolitan Water District and the adjacent territory including the city of Worcester, is well illustrated by considering what is likely to happen in this territory should a dry period occur within the next 10 to 15 years, assuming that all available sources, both of the district and the other cities and towns, should be used to their fullest practicable capacity, and assuming also that a new supply of 33 000 000 gal. per day will be introduced from the Ware River to be referred to later as speedily as practicable. The safe yield of present sources of supply for the Metropolitan District alone is sufficient until the year 1928 if no other municipalities are added. If a severe drought should occur at about that time the district supplies might be exhausted as early as 1926. If a supply of 33 000 000 gal. per day should be introduced from the Ware River it would be sufficient for the district alone until the year 1935, but if the city of Worcester and half of the cities and towns in the neighborhood of the district which seem likely to need water with the next dry period should be added to the district the supply would be sufficient only until about 1932. Even if it were assumed that there will be no increase whatever hereafter in the consumption of water per capita in the Metropolitan Water District, the consumption of water in that district including the nearby cities and towns likely to require water therefrom and the city of Worcester would reach the safe capacity of all available sources, even with an additional supply of 33 000 000 gal. from the Ware River, by 1936. In other words, if a supply of 33 000 000 gal. per day should be introduced as soon as possible from the Ware River, a still further supply would be needed by 1931, and even if the consumption of water per capita in the present Metropolitan District can be kept from increasing beyond the figure of 1920, a further additional supply would be needed by 1936, even though all of the present available sources, so far as possible, should be retained in use.

Circumstances which Affect the Selection of Water Supply for the Metropolitan District.

There have been marked changes in the conditions affecting the use of inland waters in Massachusetts since the earlier water supply projects were considered. Massachusetts is an industrial State and its rivers are most important sources of power, the value of which has increased with the great increase that has taken place in the demand for power and the cost of fuel. But not only is the water of the rivers of great value for power but also for manufacturing and mechanical uses; and large quantities of water are used for these purposes in some of the more important industries of the State. Furthermore, with the growth in population and the increase in industry, especially within the past 30 years, there has been a great increase in the quantity of sewage and industrial wastes requiring disposal in the river valleys of the State.

River sanitation had hardly been thought of in this country 50 years ago, and the first general laws of importance relating to that subject were not enacted until 1886 and 1888. Knowledge of its requirements was still in its infancy when the investigations for the present Metropolitan water system were begun nearly 30 years ago and even at the present day the progress attained still leaves much room for improvement.

While works for treating sewage and manufacturing wastes are common as compared with the conditions 30 years ago, these wastes still find their way into the streams in some cases with more or less effective purification but commonly with none at all. Under these conditions, the question of the diversion of water from a given watershed may affect in a much greater degree than was the case 30 years or more ago the conditions in the valley of a river below a proposed point of diversion. These considerations have a most important effect upon the availability of many of the rivers of the State for use as sources of water supply.

The diversion of the flow of water from any considerable portion of the watershed of many of the streams, besides the effect it may have on the use of the streams for other purposes, especially in the drier part of the year, means a reduction in the water available for the dilution of effluents discharged lower down and an increase in the difficulty and expense of maintaining proper sanitary conditions in such streams. In some of the river valleys great changes have taken place in respect to the use, and it must be admitted the abuse, of the streams in the past 30 years which require careful consideration in connection with any plan for diverting water from such streams for water supply uses, since such diversions may involve large claims for damages wholly aside from the use of the streams for power or other industrial purposes. These considerations affect materially the advantages of the use of some of the proposed sources of water supply considered available at an earlier day.

Sources of Water Supply Considered.

The Charles River is one of the streams which have been mentioned as possible additional sources of water supply for the Metropolitan Water District. It is an excellent example of the changes that have taken place since its use was first seriously proposed as a source of water supply for the city of Boston in 1874. The river above the Boston Manufacturing Company's dam at Waltham drains an area of about 248 sq. mi., but as one-third of the flow is diverted into Mother Brook at Dedham, the effective watershed at Waltham is only 182 sq. mi. At the present time 17 cities and towns obtain their water supply from this watershed, the population of these municipalities and the quantity of water used in each in 1895 and in 1920, so far as information is available, being shown in the following table:

Supply Introduced in.	Municipality.	Population Supplied.		Consumption in Gallons per Day.	
		1895	1920	1895	1920
1873	Waltham	20 876	30 915	1 222 000	1 960 000
1856	Cambridge	81 643	109 694	6 074 000	11 435 000
1874	Lincoln	1 111	1 042	144 500*	221 000
1896	Weston	.....	2 282	.....	159 000
1884	Wellesley	4 229	6 224	175 000	536 000
1876	Newton	27 590	46 054	1 801 000	3 687 000
1890	Needham	3 511	7 012	139 000	450 000
1875	Brookline	16 164	37 748	1 318 000	3 451 000
1881	Dedham	7 211	10 792	419 000	799 000
1891	Holliston	2 718	2 707	79 000	119 000
1891	Millis	1 006	1 485	33 200*	61 000
1889	Medfield	1 872	1 900**	56 000*	76 000*
1911	Medway	2 913	2 956	90 300*	122 000
1881	Milford & Hopedale	10 336	16 248	527 000	987 000
1884	Franklin	5 136	6 497	201 000	513 000
1908	Wrentham	.....	2 808	.....	89 000
		186 316	286 364	12 279 000	24 665 000

* Estimated. ** Omitting asylum population.

Besides the amount diverted by the water supplies, large quantities of water are diverted from the lower part of the watershed by the system of sewers in Waltham, Newton, West Roxbury, Dedham and Wellesley. The only site where it would be possible to construct a large storage reservoir within the Charles River watershed is in the area which includes the Medfield Meadows, so called, extending from South Natick to the neighborhood of Medway. The area of the watershed tributary to a reservoir in this location would be about 156.3 sq. mi.

The reservoir would hold about 9 000 000 000 gal. with an average depth of 9 ft., or 18 000 000 000 gal., with a 12-foot depth, and might furnish a safe yield of from 63 000 000 to 93 000 000 gal. per day according to the height of the dam.

Obviously the diversion of all of the water from the drainage area above this proposed dam would greatly damage the water supplies along the river below and the requirement that one-third of the flow of the river must be allowed to flow through Mother Brook introduces another complication. The necessity of maintaining proper sanitary conditions in the river below, and especially in the Charles River basin, is still another requirement, besides the need of allowing enough water to run for the use of the factories and mills along the stream. Certainly any taking of water from the upper part of this valley now would have to be a limited one and, taken in connection with the cost of the proposed reservoir, together with the cost of properly purifying the water and conveying it to the district, would unquestionably be excessive in view of the quantity of water likely to be obtained.

Among other near-by rivers which may be considered as possible sources of additional water supply are the Shawsheen, the Ipswich and the Merrimack. The Shawsheen was considered many years ago and rejected as impracticable. The Ipswich River has already been divided up between the cities of Lynn, Peabody, Salem and Beverly and the towns of Danvers, Saugus, Reading and Middleton, and the question has been raised as to whether it may not be a proper source for some of the municipalities in the Merrimack valley. With the highest practicable development a very large part of the supply from this source would be required for the cities and towns in the densely populated county of Essex, and little would remain for the use of the Metropolitan Water District. The use of the Merrimack River as a source of water supply for the Metropolitan District was carefully investigated by the State Board of Health in 1895 and rejected for reasons which proved satisfactory to the Legislature of that day. Far more serious objections would arise to any proposition to use that river as a source of water supply for the Metropolitan Water District at the present time, even assuming that the inhabitants of the district would be willing to use so polluted a water for drinking even with the best system of purification that it would be practicable to devise. The use of the water of this river for water supply purposes would require a thorough system of filtration and would make necessary the pumping of all of the water drawn therefrom for the supply of the district. Furthermore, the use of that source would eventually not only reduce materially the amount of water available for power and industrial uses at Lowell and Lawrence, which would have to be replaced by power from other sources, but would also involve the installation of power plants for pumping the water required by the district and the use of an ever increasing quantity of fuel for the purpose or the purchase of power which would otherwise be available for other uses. The taking of this water would also involve serious interference with the flow of water available for maintaining proper sanitary conditions in this river which has already been the source of complaint below the proposed point of diversion. The use of this river was rejected for excellent reasons

many years ago and its use would obviously be more objectionable today. The waters of many rivers in the eastern part of the state like the Aberjona River and its impounding reservoir, the Upper Mystic Lake, are unfit for domestic use. In this class are the Neponset and Blackstone rivers and the Nashua River and its North Branch, while the Squannacook — which is the only large branch of the Nashua suitable for water supply — would not furnish sufficient water to pay for its development for the Metropolitan Water District.

There are no practicable sites for storage reservoirs on the Concord and Sudbury rivers, and of the large natural lakes and ponds which might otherwise be available, Lake Winnepesaukee is in New Hampshire and Assawompsett and its tributary ponds are used, and will be needed, by the municipalities of Bristol County.

The Assabet River.

In the report of the State Board of Health in 1895 containing the plan for the present Metropolitan water supply, certain tributaries of the Assabet River are mentioned for use in the first probable extension to the Metropolitan water supply system when an additional supply should become necessary. The investigations at that time indicated that the waters of several small streams in the upper part of the Assabet River watershed, through which the Wachusett Aqueduct passes in its course to the Sudbury Reservoir, could be utilized for supplementing the Metropolitan water supply by diverting them into the aqueduct through some six separate connections. The watershed of one of these streams, however, is used as a source of water supply for the town of Northborough and that of another which drains an area along the Boston and Albany Railroad above Westborough has become much more populous than was the case years ago. Furthermore, the sewage disposal works of the town of Westborough are located in this valley just below the proposed point of diversion, and if the flow of this watershed were to be diverted as proposed little water would be left in the river during the drier part of the year to dilute the effluent from those works. There has been much litigation over the condition of this river below the sewage disposal works in past years and under the circumstances the diversion of water from this tributary at the present time is inadvisable. Omitting these areas, including one other small area which would naturally be grouped with them, the total remaining watershed is 21.9 sq. mi., and if all of the water possible should be diverted from this area for the use of the Metropolitan Water District, the additional safe yield thereby obtained would not exceed about 17 000 000 gal. per day.

The Assabet River watershed below the areas drained by these streams contains several large towns in which are located important factories and mills, some of which use large quantities of water in their processes; while one, the woolen mills at Maynard, uses at times nearly the whole dry-

weather flow of the river for such purposes. Furthermore, in addition to the effluent of the sewage disposal works of the town of Westborough, that of the town of Hudson is also discharged into the river; and similar disposal is made of the effluent from small sewage disposal works in the town of Maynard, which flows into one of the tributaries of the river. There are also works for treating manufacturing wastes at some of the mills, the effluent of which is discharged into the stream. This river has been the source of much complaint in past years on account of pollution by sewage and manufacturing waste and considerable litigation has resulted therefrom. Its condition finally became so objectionable that the Legislature passed a stringent law designed to prevent its further pollution. The conditions now existing in this valley are such that if the whole flow of water from the portion of its watershed in question were diverted from the river the condition of the stream would no doubt become more objectionable. Under the circumstances the damages which would be likely to result from the taking of the entire flow of these streams, in addition to the damage to water power alone, would be likely to be large, and it is not at all probable that so complete a taking of water would or should be authorized by the Legislature at the present time. The amount of water which could be obtained from this source would consequently depend upon the limit of taking which might be imposed by the Legislature. Limited takings are common enough in the legislation of Massachusetts and the advisability as a general policy of limiting the quantity of water that may be diverted from most of the watersheds of the State, sufficiently to prevent any serious diminution of their flow in the drier part of the year, will hardly be questioned by anyone having a thorough knowledge of the conditions which exist in most of the river valleys. If the district should be authorized to take all of the flow of these streams in excess of 0.35 of a c.f.p.s. per square mile of watershed, or about 225 000 gal. per square mile per day, which is the approximate limit of taking in the case of the Ipswich River, but without other limit as to the quantity or time of diversion, the safe yield obtainable from the use of these streams in the Assabet River watershed would be about 11 000 000 gal. per day. This amount would be sufficient for the needs of the district for no more than about three years after the capacity of the present sources had been reached and the amount obtainable would hardly pay for the trouble and expense of the taking. Furthermore, the taking might be even further restricted and in that case the amount of water available would be less. With conditions as they are it has seemed inadvisable to recommend the taking of any water from the Assabet River, though it may become necessary to use water from some portions of this watershed in case an emergency should arise since water can be diverted from these streams more readily probably than from any other available source.

The Ware and Swift Rivers.

In the report of the State Board of Health upon a Metropolitan water supply in 1895 it was recommended that a second source of considerable size could be tapped when the Wachusett Reservoir supply on the Nashua River could be augmented by building a tunnel to Coldbrook on the Ware River and diverting the water from a drainage area of about 100 sq. mi. It was further suggested in that report that later on a reservoir could be built in the Swift River valley, and the water also delivered to Wachusett Reservoir by gravity through an extension of the tunnel from Coldbrook to the Swift River. Reference was also made to the possibility of using later as supplementary supplies water from the Deerfield and Westfield rivers in the extreme western part of the state.

When the recent investigation was undertaken great changes had taken place in the conditions affecting the use of these rivers as sources of water supply for the Metropolitan Water District. The population in the rural areas throughout the State has declined steadily for many years while, on the other hand, the industries along many of the river valleys have grown and the population has grown with them, and the prosperity of these valleys has become almost wholly dependent upon the prosperity of the industries along the rivers. In the Ware River watershed little change of importance has taken place in the neighborhood of Coldbrook or above it, in the region from which it was proposed in 1895 to take an additional water supply for the Metropolitan Water District; but in the valley of the Ware River below Coldbrook, and in that of the Chicopee River of which the Ware is one of the principal tributaries, the industries have become much more important than in 1895. And the water is used not only for power but for various manufacturing processes in the mills and factories along the stream. Furthermore the dry weather flow of the rivers is depended upon for the effective dilution of the sewage and manufacturing wastes which after more or less purification in some cases, and in others none at all, are discharged directly into the stream. The total drainage area of the Ware River at its mouth is about 221 sq. mi., and if all of the water were diverted from 100 sq. mi. above Coldbrook, the flow of the river would be diminished nearly one-half in the neighborhood of its mouth and in an increasing proportion from point to point farther up stream, until in the vicinity of the proposed dam there would be little or no flow after the full supply of this source came to be required by the district, except such amounts as might be wasted at times of high freshets, usually in the early spring. There is no question that, in order to avoid excessive costs and damages, and especially to avoid permanent injury to the prosperity of this valley, it will be necessary to limit the amount of water to be diverted from it, especially in the drier part of the year. Since it was deemed inadvisable to divert any part of the Assabet River watershed for the permanent use of the Metropolitan Water District, and since only a limited taking of water from the Ware River is

likely to be authorized, the question of obtaining a material addition to the water supply of the Metropolitan Water District required the consideration of other additional sources.

The source suggested by the State Board of Health in 1895 for the next extension beyond the Ware River was the Swift River, upon which the preliminary studies indicated that a very large storage reservoir could be constructed by means of a dam above West Ware about 8 miles from the mouth of the river at such a height as to make practicable the delivery of nearly all its storage into Wachusett Reservoir by gravity. While the effect of the diversion of the whole flow of the Swift River might be comparatively small, so far as the remaining drainage of that river below the proposed dam is concerned, the effect upon the Chicopee valley below, of which the Swift River is one of the three principal tributaries, would be most important, and in this case again the taking of the whole flow of the stream was deemed inadvisable, on account of the large damages that might result and the possible injury to the prosperity of this important industrial district.

While the taking of the whole flow of the Swift River would be objectionable, the possibilities of the great reservoir which might be constructed in the Swift River valley, afforded by the circumstances of its location, presented an opportunity rarely offered to reverse the usual practice; and, instead of taking the entire flow or even the larger part of the flow of any one or two streams, to take the freshet flows of a large area by combining a number of streams together, and thus avoid any interference whatever with flows which are materially less than the average and which prevail ordinarily for more than half the year; that is, to take from the top of the time flow curve instead of the bottom.

Conservation of Flood Waters by Diverting only the Higher Flows from Large Areas.

The distribution of the rainfall in New England is such that the greater part of the water yielded by the rainfall and melting snows passes off in the streams in the winter and spring and, while the river valleys are ordinarily inundated for a few weeks in the latter season, the streams usually shrink to comparatively small dimensions for many months in the summer and fall. The Swift and Ware rivers and the other rivers in that region are no exceptions to this rule. Measurements of the Swift River, at a measuring station maintained by the U. S. Geological Survey in coöperation with the State of Massachusetts for several years at West Ware, a short distance below the proposed main dam in this valley, have shown a maximum flow in the period extending from August 1912 to December 1921 as high as 8 000 000 gal. per square mile per day and a minimum below 80 000 gal. Wider variations would no doubt have been shown if records of a longer period were available. There are ordinarily many weeks in the winter and

spring, and also periods in the summer and autumn in some years, when the flow of water exceeds the capacity of the wheels in most of the power plants on the Swift and Ware rivers and on the Chicopee River below them; and water runs to waste over all of the dams on these streams. On the other hand, in the summer and autumn the flow usually falls below the capacity of the wheels, and a part of the power necessary for operating machinery in the factories and mills must in many cases be obtained from other sources or from auxiliary steam plants maintained for the purpose.

The diversion of the water of the higher flows into an adequate storage reservoir, would diminish the freshets, which interfere at times with the operation of power plants and cause injury in other ways. The storage afforded by the proposed reservoir in the Swift River valley would be so great that with that reservoir in use it would be practicable so to regulate the discharge into the Swift River that instead of a variation of flow ranging from 80 000 to 8 000 000 gal. per square mile per day, a nearly uniform quantity of water could be discharged to the mills below at all times, in years of excessive rainfall and in years of drought, with comparatively little waste in proportion to the whole quantity used.

If a supply should be obtained for the Metropolitan Water District by taking the entire flow of the Ware and Swift rivers for the use of the district, the damage done to the mill powers and other interests in the valleys below might not be serious in the beginning but it would have to be paid for, though a part of the water would be available for many years for the use of its former owners. On the other hand, by taking advantage of the storage afforded by the great reservoir in the Swift River valley, and retaining therein only the higher flows above the quantities of water which are required by the majority of the industrial power plants, the water flowing in periods of excess could be diverted for water supply uses and the remaining water allowed to flow past the dams in varying quantities, as it does to-day, or in such quantities and at such times as might be mutually agreed to be to the best advantage of those who use the water for power. In this way the damages to water powers could be greatly reduced, the variations in the flow of the river could be regulated, and injury to the prosperity of the valleys prevented.

Utilizing the Flow of Other Rivers in Connection with that of the Swift and Ware.

Following out the idea of combining the flows of several rivers and taking only the higher flows, which are now of little or no value and usually a detriment to the valleys which the rivers drain, studies have been made of the other rivers from which water might be diverted into a proposed reservoir in the Swift River Valley. The results of these studies indicate that, in addition to the waters of the Ware River and of parts of the watershed of the Lower Ware, so called, between Coldbrook and Gilbertville,

water could be diverted into the proposed reservoir from large parts of the watersheds of the Millers, the Quaboag, the Deerfield and the Westfield rivers. In fact, the total drainage area which could ultimately be made tributary to this reservoir amounts to more than 1 200 sq. mi. and is equivalent to about one-sixth the total area of the State.

With the amount appropriated for the investigation it was possible to make an adequate preliminary study of all of the watersheds which might be utilized in connection with this plan. The nearest of the rivers to the proposed reservoir, aside from the Ware, are the Quaboag and the Millers rivers, and of these the Millers would apparently be the more favorable for use since it has a larger watershed than the Quaboag and requires a shorter conduit for connection with the proposed Swift River Reservoir. The Millers River was not carefully considered as a source of water supply at the time of the previous investigation because of the fact that one or two towns of considerable population are located within its watershed and might cause objectionable pollution of the water. Further consideration of the possible use of this watershed shows that the larger of the towns is but little greater in size than the largest municipality within the present Metropolitan watershed area, and if the largest of the towns in the latter watershed, which is situated at the head of the Sudbury Reservoir can be so dealt with as to prevent its being a menace to the Metropolitan water supply at the present time, it seemed possible that the drainage from the towns on the Millers River might also be cared for satisfactorily,— in view of the circumstances,— if it should be desirable to use that stream for water supply purposes. Accordingly, studies were made to determine the practicability of combining the freshet flows of the Millers River with those of the Ware and Swift in the Swift River Reservoir. The results of these studies show that by combining the flows of the Ware, Swift and Millers rivers, it will be necessary, in order to secure an additional water supply of 200 000 000 gal. per day for the Metropolitan Water District, to divert only those flows which are in excess of 1.2 c.f.p.s. per square mile of watershed or the flows in excess of about 775 000 gal. per square mile per day. Such an additional supply would meet the requirements of the Metropolitan Water District and the municipalities which may be dependent thereon for water for a very long time in the future.

In this study a considerable portion of the flow of the Lower Ware River, so called, that is, that portion of the watershed of the Ware River, below Coldbrook, has been included. While there have been no material changes in the valley of the Ware River above Coldbrook, a region which is very sparsely populated, the conditions in the valley of the river below Coldbrook have changed materially and the plan of diverting water directly from the Ware River in this part of its watershed would be impracticable at the present time on account of the pollution of the river; but it will be feasible to divert the freshet flows of the more important streams in this watershed having an aggregate area of at least 20 square miles, and probably

much more, by diverting these flows directly into the shafts of the proposed tunnel from the Swift River to the Wachusett Reservoir at points where the tunnel passes beneath these areas, whenever it may be deemed desirable to do so.

Cost of Utilizing the Freshet Flows as Compared with More Complete Taking of Smaller Watersheds.

Having determined that an adequate water supply for the Metropolitan district, and the cities and towns likely to be dependent thereon for water for many years in the future, could be obtained by the development of such a plan as has been described, the necessary studies were made to determine the advantages and comparative cost of developing a water supply in this way, as compared with the cost of the more complete takings of a smaller area of watershed common in an earlier day. In making these estimates, it has been assumed that the limit of the taking of water from these streams would be placed higher than in the case of the Ipswich River, where the maximum taking was limited to flows in excess of about 230 000 gal. per square mile of watershed per day. The conditions in the valley of the Ware River, and of the Chicopee River below the junction with the Ware River, are very different from those along the Ipswich River below the lowest point of taking on that stream. The Ipswich River valley below these takings is very sparsely populated with no factories or mills or villages of any notable size within it until the river reaches Ipswich, where it discharges into the sea. In populous valleys like those of the Ware and Chicopee rivers, a limit should necessarily be placed much higher than in the case of the Ipswich River, if serious injury to the prosperity of these valleys is to be avoided. It has been assumed in these estimates that the limit might be about twice as high as in the case of the Ipswich River; that is, that the takings in the valleys of the Ware and Swift rivers might be limited to flows in excess of about 500 000 gal. per square mile per day, or about 0.8 of a c.f.p.s. per square mile. With this limitation the estimated cost of a water supply to the Metropolitan Water District, from the Ware and Swift rivers combined, was found to be practically the same as the estimated cost of a water supply from the Ware, Swift and Millers rivers combined with a taking in excess of 775 000 gal. per square mile per day. Since there would be much less interference with the flow of the streams in the case of this latter taking, there is no question as to which method is the better for the State to adopt.

As a result of these investigations the plan recommended for obtaining an additional water supply for the Metropolitan Water District is the construction of the proposed reservoir in the Swift River valley, the diversion of the higher flows of certain portions of the Millers and Ware rivers, into the Swift River Reservoir and the construction of a tunnel to convey the water to Wachusett Reservoir, and thence to the district. This scheme

lends itself remarkably well to the growing needs of the district and of the other communities requiring water in the eastern part of the State. With the present rate of growth and increase in the use of water, an additional water supply will be needed by the district soon after 1928, the exact time depending upon the uncertain factor of the rainfall in the period when the consumption of water in the district reaches the safe capacity of the works. It will be practicable if work is begun without delay to construct the first half of the tunnel as far as Coldbrook within the next 6 years, and thus make available part of the freshet flows of the Ware River with which the safe yield of the Metropolitan sources would be increased by about 33 000 000 gal. per day, assuming that the taking of water from the watershed of the Ware River above Coldbrook would be limited to quantities in excess of 1.2 c.f.p.s. per square mile of watershed. The plan also makes possible an additional water supply for the city of Worcester. It is possible to obtain water for Worcester from one of the tributaries of the Quinepoxet River, though this is likely to be objected to by the Metropolitan Water District, while a more favorable plan is that of pumping directly from Wachusett Reservoir for the supply of the city of Worcester as was done in an emergency some 10 years or more ago. Under the plan now proposed the tunnel would pass beneath the upper end of one of the tributaries of the new Pine Hill Reservoir, and water can be pumped from the tunnel into this tributary for the water supply of the city of Worcester if desired.

While the safe yield of the Metropolitan sources would be increased 33 000 000 gal. with the completion of the first section of the tunnel, the safe yield of the Ware River watershed above Coldbrook would be increased to some 47 000 000 gal. per day with the completion of the Swift River Reservoir and a tunnel thereto, under the same taking, since the extension of the tunnel would make it practicable to store a part of the water in the reservoir on the Swift River which would go to waste while only the lower or Ware-Wachusett Section was in use.

There is no doubt that the diversion of the freshet flows of the Quaboag River into the Swift River Reservoir in the beginning would make practicable a limit of taking somewhat higher than suggested in the report presented. The question whether it would be advantageous to make this diversion in the beginning, or to divert the freshet flows from some of the smaller tributaries of the Ware River below Coldbrook requires further consideration and can be postponed to a later time.

The Swift River Reservoir.

The Swift River is the westernmost of the three streams which unite in the neighborhood of the village of Three Rivers in the town of Palmer and form the Chicopee River. These three streams with their drainage areas are as follows:

Swift River	213 square miles
Ware River	221 square miles
Quaboag River	210 square miles

It is practicable to create a reservoir in the valley of the Swift River which would have about half the area of Lake Winnepesaukee by constructing a dam across the main river at the boundary line between Enfield and Ware and a secondary dam or dike in the Beaver Brook valley about 3 miles northeast of the main dam.

The Main Dam and Dike.

At the site of the proposed main dam the bed rock is overlaid by a deep deposit of gravel and sand, porous and water-bearing, and a form of construction carried to bed rock will be necessary as the overlying material cannot be made impervious to water. The proximity of great quantities of suitable material indicates that an earthen dam with a core wall of impervious material will be the most appropriate form of construction under the circumstances. An excellent location for a spillway and overflow channel is found beyond the rocky hill at the westerly end of the dam where the waste water will be returned to the river well below the dam and safe from possible injury to the dam or other structures. The conditions for constructing a dike at the divide between the Swift and Ware rivers are not satisfactory, but a suitable site for the dike is found in the valley of Beaver Brook about a mile south of the divide where the conditions are similar to those at the site of the main dam, and though its length will be less, the form of construction proposed is similar.

Some of the principal dimensions of the proposed structures are shown in the following table.

Dimensions of Main Dam.

Elevation of flow line above present surface of river	147 ft.
Elevation of flow line above bottom of rock gorge	253 ft.
Width of gorge at flow line	2 700 ft.
Height of top of dam above flow line	18 ft.
Width of dam at top roadway	36 ft.

Dimensions of Beaver Brook Dike.

Height of flow line above present brook	115 ft.
Height of flow line above bottom of rock gorge	260 ft.
Length of dike at flow line	2 150 ft.
Height of top of dike above flow line	18 ft.
Width of dike at top roadway	36 ft.

The upstream slopes of both dam and dike would be somewhat less steep than 1 to 3 and the downstream slopes somewhat less steep than 1 to 2.5.

Character of the Proposed Reservoir Area.

The reservoir would contain a number of semi-mountainous islands, rocky and for the most part covered with forest at the present time; and it would be necessary for the protection of the water to acquire all of the islands, together with lands about the margin, in order to keep them

free from population and from uses which might be objectionable in the neighborhood of a reservoir used as a source of public water supply.

The dimensions of the reservoir, tributary drainage area and other facts concerning it are given in the following table:

Area of water surface	39	sq. mi.
Area of watershed, Swift River	186	sq. mi.
Area of watershed divertible from Ware River	130	sq. mi.
Area of watershed divertible from Millers River	*220	sq. mi.
Total capacity	410 000 000 000	gals.
Length	17	mi.
Maximum width	4	mi.
Total length of shore line not including islands	86	mi.
Maximum depth	150	ft.
Average depth	51	ft.
Length of railroads flooded	15.9	mi.
Length of highways flooded	106	mi.

Population on the Reservoir Area.

In the construction of the proposed reservoir it would be necessary to remove practically the entire population of three towns and a considerable population would be affected in three others, while the habitations of a few people in five other towns would also probably have to be acquired. The towns affected, together with their population in national census years since 1880, are given in the following table:

Town.	1880.	1890.	1900.	1910.	1920.	Estimated Population in 1920.	
						Within Proposed Swift R. Res.	Within Area of all Probable Takings.
Enfield	1 043	952	1 036	874	790	694	790
Dana	736	700	790	736	599	331	378
New Salem	869	856	807	639	512	60	83
Pelham	614	486	462	467	503	20	36
Greenwich	633	526	491	452	399	393	399
Prescott	460	376	380	320	236	63	236
Hardwick**	....	....	....	....	....	30	65
Belchertown**	....	....	....	....	....	4	26
Shutesbury**	....	....	....	....	....	3	17
Petersham**	....	....	....	....	....	7	10
Ware**	....	....	....	....	....	0	8
Totals	4 355	3 896	3 966	3 488	3 039	1 605	2 048

The foregoing table indicates that the habitations of somewhat more than 2 000 persons would have to be removed in the construction of the proposed reservoir as against 1 711 in the case of the Wachusett Reservoir.

*This area includes certain small watersheds from which the water supplies of Ashburnham, Gardner, Winchendon and Athol are taken.

** Population of these towns very slightly affected.

The assessed value of real estate in the six towns most seriously affected in the years 1901, 1914 and 1920 is shown in the following table:

Town	1901	1914	1920
Enfield	$414 890	$470 680	$472 440
Dana	248 957	344 441	413 395
New Salem	246 760	328 600	409 910
Pelham	164 799	338 903	431 165
Greenwich	175 915	210 500	295 345
Prescott	139 012	171 322	176 905
TOTALS	$1 390 333	$1 864 446	$2 199 160

An examination of the area to be flowed shows that it contains in all 1 040 buildings besides 18 abandoned and 66 in ruins or with their foundations only in evidence. The character of these buildings is shown in the following table:

Mill structures	14	Houses, occupied	463
Stores in use	38	Houses, vacant	30
Churches	6	Barns, in use	381
Schoolhouses	13	Barns, vacant	18
Other public buildings	2	Camps and summer cottages	61
Railroad stations, Freight houses, etc	14	TOTAL	1 040

The total number of occupied dwelling houses as shown by the above table is 463, or about 12 per square mile, as compared with 224, or about 35 per square mile, on the area taken for the Wachusett Reservoir.

A survey has also been made to determine the character of the areas to be flooded and the present uses of the land. These statistics are shown in the following table:

Orchards	51 acres
Pasture and open land	2 118 acres
Swamp and meadow	2 338 acres
Scrub and young growth	7 889 acres
Timber land	6 845 acres
Water surfaces	1 233 acres
Cemeteries	11 acres
Unclassified lands such as village and cultivated land, highways and railroads	4 385 acres
TOTAL	24 870 acres

Treatment of the Reservoir Area.

The greater part of lands that will be covered by the proposed reservoir are at present sandy plains covered with brush or wood and having a very thin surface layer of loam. Swamps containing peat are exceedingly rare, the aggregate area of such deposits amounting apparently to less than 700 acres. A large part of the swamp and meadow land is low ground between the main stream and the uplands, kept in a swampy condition in many cases by the ground water percolating from the gravelly lands adjacent. The preparation of this great area for reservoir purposes by the removal of all vegetation and of all surface soil besides would be impracticable on account of the excessive cost, and is unnecessary in the existing circumstances. The land should be cleared of bushes and trees and all organic matter destroyed so far as practicable. It is probable, moreover, that over large areas even the surface soil can be reduced largely to ashes, so that by this process the small amount of organic matter that remains is likely to have little permanent effect upon the quality of the water of this great basin. In the earlier years, after the area is first flowed, the water will doubtless have a noticeable color, and a considerable quantity of organic matter will be taken up by contact with the material in the bottom of the reservoir, but this condition is unlikely to affect the water materially beyond the first few years. It will take several years to fill the reservoir, and during much of that time there is no doubt that water of such quality can be obtained from it that after subsequent storage in Wachusett Reservoir the quality of the water of the latter source would not be materially affected thereby, since the water need be drawn in the earlier years from the Swift River Reservoir only at times when the quality is at its best. The capacity of the proposed reservoir is such, in proportion to the size of its watershed, that the water stored there will eventually become thoroughly bleached and probably nearly or quite colorless, and while it may be affected at times in the earlier years by growths of organisms and the objectionable tastes and odors which result therefrom, the use of the reservoir at such times can be avoided.

With the increasing demand for water of the best quality, it is possible that most surface waters, no matter how free from probable danger of pollution, will be filtered before delivery to consumers, and this may sooner or later be the case with water supplied from the Wachusett system, but such a demand seems unlikely to arise for many years.

If it should ever be found desirable to improve the quality of the water of the proposed Swift River Reservoir by filtration before discharging it into the Wachusett Reservoir, rather than to filter all of the water supplied from the latter source, it would be practicable to filter it on lands in Oakdale adjacent to Wachusett Reservoir. But it is not probable that the water of the proposed Swift River Reservoir would differ materially from that of the Wachusett Reservoir after the first few years.

Tunnel from the Proposed Swift River Reservoir to Wachusett Reservoir.

The divide between the Wachusett Reservoir and the watersheds of the Ware and other rivers to the west rises to a height of over 1 000 feet above sea level, a height which it maintains generally for many miles from the northerly nearly to the southerly boundary of the State. This high divide must be pierced by a tunnel in order to bring water from the Ware or Swift rivers into the Wachusett Reservoir, and this connecting link between the present and the proposed supplies will be a most important item of construction.

The tunnel as designed will leave the Swift River Reservoir about half a mile south of East Pond at the foot of a steep rocky hill rising some 400 feet above the floor of the Swift River valley east of the village of Greenwich, and will run northeasterly to the neighborhood of Coldbrook in the Ware River valley, whence it will turn to the east and follow an easterly course to the Wachusett Reservoir.

The tunnel from the Swift River valley to the Wachusett Reservoir will pass so close to Coldbrook on the Ware River that the slight change in alignment made necessary to provide for the diversion of the water of this river directly into one of the tunnel shafts would have very little effect on the length of the line. Since the control works would be located at the Wachusett end of the tunnel, the tunnel itself would become in effect a part of the reservoir, and floods from the Ware River would flow back through the tunnel and be stored in the Swift River Reservoir whenever necessary.

As previously stated, it would be possible, whenever desirable, to divert the flood flows from several small watersheds, having an aggregate area of 19 square miles or more, tributary to the Ware River below Coldbrook into the tunnel at various shaft heads. These connections are not included in the preliminary estimates, however, because the expense of their construction would probably not be justified for many years.

The total length of the proposed tunnel to the Swift River Reservoir is about 25.1 miles. It would be located in rock, and the surface indications are favorable to construction by methods known and tried in many similar cases, but as many of the construction shafts must be deep, it is desirable, for the sake of economy, that they should be spaced at intervals of 3 or 4 miles, and probably at least four years will be required for actual construction to get the first water from the Ware River at Coldbrook into the Wachusett Reservoir. Delay in beginning the construction of this tunnel, which would require more rapid work, would mean a serious addition to the cost.

The cost of such a tunnel and the time required for its construction make it advisable to build it large enough to carry as large a quantity of water as can probably be utilized from the Swift River Reservoir, developed

as ultimately proposed, since the larger tunnel will cost less in proportion to its size than a small one. Accordingly, for the purpose of estimating the cost, this diameter has been taken at 12 feet 9 inches. With this diameter, in a series of dry years, which might cause the main reservoir to be drawn down 55 feet, or to about elevation 474, there would still remain sufficient head on the tunnel to enable it to carry 500 000 000 gal. per day. The lowest gate sill in the intake gatehouse has been designed at elevation 435, which is about the floor of the main portion of the Swift River valley. This will allow an initial supply to be obtained the first year that the storage of water is begun, and would make it practicable to draw nearly the maximum storage of the proposed Swift River Reservoir into the Wachusett Reservoir. At its lower end the invert of the tunnel as proposed would be at grade 370, the outlet of the tunnel being at Oakdale at the upper end of the Wachusett Reservoir.

Aqueduct for Millers River Diversion.

Reference has already been made to the proposed diversion of water from the Millers River. This would be accomplished by a tunnel and aqueduct leading from diversion works just above Athol to Eagleville Pond, an existing millpond on the Millers River watershed just north of the divide between the Swift and Millers River drainage area, and thence by a channel cut through the divide from the southerly end of that pond into the Swift River Reservoir. For the purposes of this estimate the tunnel and aqueduct to Eagleville Pond is designed at about 11.5 feet in diameter, and would be capable of diverting flows in excess of the normal undiverted flow of the river up to and including 5 cubic feet per second per square mile. The watershed of the Millers River above the proposed point of diversion is, as already stated, 201 square miles, but the flow would be reduced slightly by the diversion of water for certain water supplies and by the removal of the effluent from the sewage disposal works in Gardner and Templeton, as well as those which may be built in Winchendon. The amount of these diversions from the higher flows of the river is small.

Estimates of Cost.

In making estimates of the cost of the proposed works difficulty was encountered on account of the constant changes in prices of labor and commodities in recent years. It was decided to base the estimates wholly upon pre-war prices, and this plan has been followed throughout. The following table shows also an estimate of the probable cost of the works on a pre-war basis plus an addition of 30 per cent to allow for conditions which may exist if the bulk of these works should be constructed within the next ten to fifteen years. In making the estimates experience in similar construction on the metropolitan water supply in recent years, on similar work now under construction for the city of Providence, and especially on

the water supply of the city of New York, has been utilized, as well as that of other cities. In every construction item an allowance of about 22 per cent has been made for unforeseen contingencies, all preliminary surveys and designs and the preparation of contracts, as well as administration, general supervision and engineering during construction.

SUMMARY OF COST ESTIMATES.

		Construction Cost and Overhead (Pre-War Basis).	Probable Cost in 1924–35 (Pre-War Basis +30 Per Cent.)
Main dam at West Ware station:			
Main embankment	$7 124 000		
Diversion tunnel and control works	1 201 900		
Spillway and flood channel	251 700		
		$8 577 600	$11 150 880
Beaver Brook dike:			
Main embankment	6 529 000		
West dike	85 000		
		6 614 000	8 598 200
Main storage reservoir in Swift River valley:			
Clearing, grubbing and fencing; Relocation and reconstruction of highways, 47 miles; Relocation of railroad, 21½ miles; Relocation of cemeteries; Relocation of transmission lines; Sanitation and forestry		5 064 300	6 583 590
Eagleville Reservoir diversion:			
Raising Eagleville dam	44 700		
New channel via Hacker Pond	108 400		
		153 100	199 030
Millers River diversion:			
Diversion dam and intake	159 400		
Aqueduct to Eagleville Reservoir	1 173 500		
Gardner and Winchendon sewer	729 400		
		2 062 300	2 680 990
Aqueduct to Wachusett Reservoir:			
Tunnel and shafts	17 457 100		
Intakes to aqueduct	376 000		
Wachusett terminal	339 400		
		18 172 500	23 624 250
TOTAL CONSTRUCTION		$40 643 800	$52 836 940
Real estate, rights of way, depreciation, business damages, diversion damages and water rights of mills and factories below points of diversion			7 109 600
TOTAL			$59 946 540

Estimated Cost of Proposed Extension to the Ware River.

The first addition to the metropolitan water supply under the plan herein proposed, which will give an additional safe yield of about 33 000 000 gallons a day, is the taking of the flow of the Ware River at Coldbrook in excess of 1.2 cubic feet per second per square mile of watershed. This involves the construction of the proposed tunnel from a shaft at the Quinepoxet River, a tributary of the Wachusett Reservoir, as far as a shaft at the Ware River in Coldbrook, including the necessary terminal works and diversion spillway at the Quinepoxet shaft near the Wachusett end.

The estimated cost of this portion of the works is as follows. This estimate does not include the simultaneous cost of any preliminary work on the further extension to the Swift River Reservoir, although this extension would need to be begun before the tunnel to the Ware is completed.

Summary of Cost Estimates.

First Extension to the Ware River at Coldbrook.

	Construction Cost and Overhead (Pre-War Basis).	Probable Cost in 1924–27 (Pre-War Basis + 30 Per Cent)
Tunnels and shafts	$8 368 600	$10 879 180
Intakes to aqueduct	297 000	386 100
Total Construction	8 665 600	11 265 280
Real estate, rights of way, diversion damages and water rights, mills and factories below the point of diversion.		778 100
Total		$12 043 380

Summary and Conclusions.

If the Metropolitan Water District continues to grow it will need an additional water supply. If it grows at a somewhat less rate than before the war and the consumption of water per capita does not increase, the safe yield of the present supplies will probably be adequate until about 1930, but if the consumption per capita continues to increase, as has been the case in the district in recent years and in practically every city in the northern part of the United States, notwithstanding the general metering of the services, the consumption of water will equal the safe yield of the sources of supply by 1928. The city of Worcester, if its past rate of growth continues, will also need a new water supply in 1928; and the most favorable source from which that city can obtain a supply under present conditions is the Wachusett Reservoir or its watershed. There are other cities and towns adjacent to the Metropolitan Water District which are now using nearly or quite all of the water which their sources are capable of yielding in years of low rainfall and which will inevitably require a water supply from the district with the coming of the next dry period. Such periods

have occurred at irregular intervals averaging about five or six times in a century, the last one in recent years ending in 1911. Ten years more, or even a longer time, may yet pass before another dry period begins, or it may begin in the present year. Just at the present time with the experience of the heavy rainfalls of recent years, especially in the summer season, it is exceedingly difficult to convince anyone unfamiliar with water supply problems that the time will come when the sources of water supply now in use will prove inadequate. Water has wasted in practically every recent year in great abundance over the dams of all of the reservoirs in such quantities as to make it appear that all that is required in order to obtain an increased water supply is to add a few feet to the top of the dam.

But the increase in the yield of a watershed obtainable by enlarging the storage is by no means directly proportional to such enlargement. While the yield of a given watershed with a storage of 25 000 000 gal. per square mile may be nearly doubled when the storage is increased to 50 000 000 gal. per square mile, on the contrary doubling the storage capacity, when the storage is equivalent to 200 000 000 gal. per square mile, in ordinary cases only increases the safe yield from 12 to 15 per cent. On the Metropolitan watersheds the storage is highly developed, especially in the case of the Wachusett Reservoir, which comprises 80 per cent of the entire storage of the system and upon which the storage developed is over 600 000 000 gal. per square mile of watershed.

It is impossible with such a distribution of rainfall as obtains in New England so to adjust the draft from a reservoir like the Wachusett as to make available all of the water which the watershed yields; for if the draft were adjusted to insure the use of all of the flow in periods of maximum rainfall, that draft would exhaust the storage in years of drought. The draft from any water system must be so arranged that the supply will be adequate in periods of drought, and in consequence there will inevitably be a waste in periods of high rainfall. Furthermore, reservoirs are not built for immediate needs and cannot commonly be built from year to year to supply growing wants; but new construction generally allows for increasing requirements for a considerable period of years; and, in consequence, in the earlier years of the use of a water supply reservoir, large quantities of water may be wasted because the draft has not reached the safe capacity of the source of supply. But as the draft becomes equal to or exceeds the safe yield of the source, years of low rainfall quickly demonstrate its inadequacy and unless provision is made in advance, shortgage inevitably results.

In the case of the water supply of the Metropolitan Water District, the consumption of water already equals the safe yield of the Wachusett and northern Sudbury sources, and further increase in the needs of the district must be supplied from the old southern Sudbury and Cochituate sources which have a combined capacity of perhaps 30 000 000 gal. per day. These sources were used regularly in the past and in the last very dry year,

1911, when Wachusett Reservoir was drawn to the lowest level thus far recorded, 40 per cent. of the supply of the district was obtained from the Sudbury and Cochituate works, chiefly the older Sudbury Reservoir and later Cochituate. The waters of these latter sources, to-day, are unsafe and objectionable for water supply purposes unless properly filtered. Filters are not yet available for the treatment of these waters; but unless provided and used before Wachusett Reservoir becomes materially depleted at the beginning of a dry period, the safe yield of the Metropolitan sources will be much less in such a period than shown by the figures presented. The calculations are based on the records of yield in the dry period which practically closed in 1911, — a period which was not as dry as others of record. If the water supply of the Metropolitan Water District is to be maintained to meet conditions of drought such as have occurred in the past, an additional supply should be available by 1928 or 1930, since the district is likely then to be using all of the water which the sources will safely yield; and if a severe drought should occur at that time, bringing demands from other cities and towns, as has been the case in past dry periods, a shortage will inevitably occur. If no unusual difficulties are encountered it will take about 6 years to construct the necessary works for diverting water from the Ware River to the Wachusett Reservoir, and from 12 to 15 years after the work is begun to make water from the Swift River available to the Metropolitan Water District.

The plan for securing an additional water supply for the Metropolitan Water District has been so designed that it lends itself in a remarkable degree to gradual development, step by step, and involves no expenditures for temporary or make-shift construction. It thus allows the details of construction to be modified by circumstances and requirements which may appear from time to time.

Beginning with the diversion of the upper portion of the Ware River watershed, the plan provides not only for extension to the Swift River but looks ahead ultimately to a much longer future and a very much larger supply. Water can be diverted into the great reservoir on the Swift River not only from its own watershed and the watersheds of the Ware and Millers rivers as proposed, but also from the Quaboag, the Deerfield and the Westfield rivers, the waters of which will flow by gravity into the great reservoir on the Swift River. The plan proposed will avoid serious injury to water powers on the rivers below by taking only the freshets and the higher flows in excess of about 775 000 gal. per square mile of watershed, per day, which means that water would be diverted in average years only about 43 per cent. of the time; while during 57 per cent. of the time the water would run in all of the rivers, as it does today: that is, from the late spring to early winter there would be no interference with the flow, unless in the case of excessive summer rainfalls when the excess would be stored in the reservoir. In very dry years the period of diversion of water would necessarily be shorter, and little water would be diverted from the rivers during

eight or nine months of the year. The requirements of the district in such periods would be drawn from the great storage in the Swift River Reservoir, which would hold an ample supply for the longest drought for a population very much greater than any which is likely to require a supply from this watershed for many years in the future. Furthermore, when an additional supply again is needed the same policy can be followed of taking freshet flows from the other rivers; and while 200 000 000 gal. per day would be obtained with the development thus far proposed, this quantity can be much more than doubled by similar takings from other available sources.

Incidental to the creation of this additional water supply, the development of water power would be made practicable at several points. At the main dam in the Swift River valley there will be a fall of about 141 ft. in discharging the water, which must be allowed to flow down the stream continuously up to the limit of 1.2 c.f.p.s. per square mile of watershed. At the Wachusett terminal of the tunnel there will be a head of about 125 ft. available for power as soon as the Swift River Reservoir is full; and this head will continue to be available for many years, diminishing in time with the increased draft through the tunnel as the draft approaches its full capacity. It will also be possible by intercepting the Quinepoxet River and thus diverting the water from one of its main tributaries into the tunnel and thence to the Wachusett Reservoir, to utilize the full power of that stream at a very small additional cost, thus restoring the power destroyed when this river was stripped of its power plants in the lower part of its course when the Wachusett Reservoir was built. Additional power will of course be created at the Wachusett dam at Clinton and at the Sudbury dam, while one or two small power developments would be available at other points. The additional power readily obtainable as an incident to the construction of these works would add very materially to the developed water power of the State.

The cost of the entire works when completed is not excessive when compared with the amount of water that will be secured thereby. The greater part of these works will be adequate for a very long period of time in the future and this consideration should be taken into account in the payment of indebtedness created for the construction of the works. The cost of the present Metropolitan water system will in all probability change but little in the next 14 years, though there will probably be a gradual increase in the cost of maintenance, while the total cost per capita will gradually decrease. In the year 1935 nearly one third of the bonds issued for the construction of the present works will become due and the cost per capita charges will then diminish rapidly for the next seven or eight years, when the bulk of the entire indebtedness will be paid. Under these conditions, in financing the proposed new works the construction of which cannot be completed in any case before 1936 even if begun at once, it will be a great advantage if the payments on capital charges are made small in the beginning,

and increased materially when payments on the original net debt begin to reduce rapidly the charge on that account in the year 1936.

The results of a careful study of the financial condition of the district as a whole and its various special divisions, indicates that the income of the district is likely to grow more rapidly than the expense, even including the cost of financing the new system, except possibly in the earlier years before the payment of the existing Metropolitan water debt; and even in that case, by a reasonable arrangement of payments of the new debt, the income of the water works should be sufficient to meet all requirements. Following 1936 the surplus receipts of the water departments will soon greatly exceed the requirements for financing the proposed new works.

In conclusion, it is worth noting that the maintenance cost of water per capita to the municipalities in the Metropolitan district, is generally less, and in most cases much less, than the cost to those municipalities which have remained outside the district and have operated independent works up to the present time. This condition was to have been expected and, even with the financing of the new works added, water will no doubt be cheaper to the inhabitants of the cities and towns of the Metropolitan Water District generally, when a long time in the future is considered, than to those outside.

Discussion.

The President. Gentlemen, this very interesting sketch of a very big piece of work is before you for discussion. I don't know how many of us are able to get an adequate idea so that we can intelligently add much this afternoon, but there are some present who have had to do with this investigation. Dr. Kelley, the Massachusetts Commissioner of Health, is present. Dr. Kelley.

Dr. Eugene R. Kelley. The speaker has mentioned one point that needs emphasis; that is in reference to the first section under the project. The first section, the construction of the tunnel to the Ware River, when built will take care of the immediate water problem for the Metropolitan District and for the city of Worcester. No one can predict exactly how long it will be before the final unit to the Swift River will be required in order to insure ample water supply at all times. We have recommended as our final conclusion, as a Commission, that the first part is imperative and should be done at once, and then we can decide by circumstances which will depend on the growth of population, the increase of consumption per capita and the meterological conditions. Of course it is only safe to assume the output of the absolutely dry years in any water supply prediction. We thought that the decision as to the construction of the final unit could be safely left to the authorities responsible for the construction, completion and putting into effect of the work, simply putting it up to them that the water should be there at the time it was needed.

I don't know as Mr. Goodnough brought out the point that our estimate indicates taking over ten — probably nearly fifteen — years from the time of the beginning of work before the water could be available through our pipes from the Swift River reservoir. Therefore you see it is necessary to allow a considerable time to be devoted to construction work.

THE PRESIDENT. Are there any men here present who are not members of the New England Water Works Association who are our guests to-day and who are interested in this problem?

DR. KELLEY. Mr. President, I would suggest that Mr. J. Waldo Smith, Chief Engineer Board of Water Supply of New York, be invited to speak.

THE PRESIDENT. I have him in mind, Dr. Kelley, as a reserve, but I want to know if there are any men who are interested in this problem, mill owners for instance, some one who may be affected by this proposed development? We would like to hear from any of you gentlemen. Mr. Smith, will you say a few words?

MR. J. WALDO SMITH. Mr. Goodnough has stated the facts so clearly that there is not much more to be said. It seems to me that the problem, reduced to its lowest terms, is: Does the district need more water and from what locality can it be best obtained? The other controlling factors are the size of the population now supplied, the probable rate of growth and the probable rate of per capita consumption. This committee has been working on this problem for two and a half years, and unless one is so imbued with supreme pessimism that he believes this district is not going to grow, or is even going to decrease in population, he must believe it is going to increase, and for this reason must have more water, and must have it in the immediate future. Then comes the question of where such additional supply may be best obtained. Whether it is best to provide a comprehensive plan, looking a long time to the future and which can be developed by successive increments, the first increment amounting to about one sixth of the cost of the entire work; or whether it is best to look only to the immediate future and develop at about the same cost a supply which by no means could ever become part of a large comprehensive plan.

I think this question has been very well answered by eleven out of the twelve members of the committee. They have signed a report recommending a comprehensive plan, and it seems to me that no other plan can receive serious consideration.

The district is very large, and in the past has had a steady growth. I believe it is going to continue to grow in the future, although perhaps at a lower rate than is estimated for many other places. It is true that the water developed at the Wachusett reservoir under the plan of 1895 has lasted longer than was then believed probable, as has been very clearly shown by Mr. Goodnough's diagrams. The rate of increase in the population which was then predicted has not been realized. In view of the experience of these fifteen or twenty years, I think that the estimated in-

creased population as laid down in this report is very conservative. In the district with which I am most familiar, I should certainly have allowed a higher rate. But as finally recommended in this report, my estimate is that the projected increase in consumption will be realized, if not exceeded in the future.

THE PRESIDENT. Prof. Whipple, can you speak on the subject this afternoon?

MR. GEORGE C. WHIPPLE.* Mr. President and Members of the Association: As a member of the joint committee that Mr. Goodnough has referred to, I have taken great pleasure in studying this great problem. No one who has been connected with it can fail to realize its magnitude and no one can fail to realize the excellent work which has been done by Mr. Goodnough and his corps of assistants, which has included a number of the members of this Association, — Mr. Brewer, Mr. Kennison, Mr. Weston, Mr. Hammond, and some others that you probably know. I have been studying this problem along with Mr. Goodnough and Mr. Smith; and being an engineer I have naturally made some estimates of my own in connection with some of these matters, as, for example, the probable future population of the district and the per capita consumption; and I am frank to say that my estimates have not agreed absolutely with those of Mr. Goodnough. No two estimates could be expected to agree exactly. I think that the growth of population will probably be not quite as great as he expects it to be; also that the per capita consumption perhaps will not increase quite as much. And yet I was not able to agree with the twelfth man on our joint board who made the minority report. His estimates of future population and water consumption seem to me to be too low. I think that this district is bound to grow in very much the same way as it has grown in the past, but at a continually lessening rate.

Now there are two or three complicating factors in this water situation which need explanation. If it were a question of the Metropolitan District alone the problem would be a good deal easier to solve than it really is. Mr. Goodnough has already referrred to the city of Worcester and its needs. This city is located near the Wachusett supply of the Metropolitan District, — in fact, its watershed is contiguous to that of the Wachusett area, — and it is very natural that as Worcester is getting short of water she should want some territory for her own supply. It seems to me that it would be most unjust to the Metropolitan District to allow Worcester to take this large fragment of the Wachusett area which she desires. It seems to me that a very much better solution is to provide a supply which can be used jointly by the city of Worcester and the Metropolitan District, and that is the reason why the Joint Board recommended the Ware River as the first extension of the District's water supply. The Ware River will help to take care of the Metropolitan District for a good many years, and it will also provide Worcester with what she needs.

(* Professor of Sanitary Engineering, Harvard University.)

Furthermore, in going west of the divide and taking water from the Connecticut River watershed, it is proposed to take simply the flood flows, not the entire stream flow; and it seems to me that this is the great outstanding feature of Mr. Goodnough's report. While not without precedent even in Massachusetts, the magnitude of this project makes it a notable recommendation. The plan is to take the flood flows only, leaving the summer flows and the low flows of the Ware River just about as they are at present, — I may say almost exactly as they are at present. I think that is a very important matter which deserves careful thought.

Then there is another element in the problem which Mr. Goodnough did not mention, — for lack of time, of course, because he could not speak of all these things in one short paper, — namely, the fact that certain of the present supplies of the District are able to furnish about 25 000 000 or 30 000 000 gal. of water which is not now satisfactory in quality. If I am not mistaken, we may place the present supply of good water in the Metropolitan District at something like 125 000 000 gal. a day. The total supply is more than that, — say 155 000 000 or perhaps 160 000 000 gal. per day, provided that the waters of the South Sudbury and Lake Cochituate are filtered. Now if it were not for the need of Worcester, filtration would perhaps be the logical step to take first, but that would not do Worcester any good. But by building the tunnel to the Ware River we can get just about the same amount of water that could be obtained from the South Sudbury and Cochituate by filtration, we can provide Worcester with what she needs, and can provide a large factor of safety for the Metropolitan District, which I believe is a good thing.

There is another factor which has not been touched upon to-day and was not mentioned, in a conspicuous way, in the report of the Joint Board, and that is the possibility of the development of a large water supply in the valley of the Ipswich River. That project has been proposed a number of times and there is reason to believe that it is a feasible project. The time is coming when the cities in that part of the state, — the Essex County cities — will need to have a great water supply of their own, and if they can make a joint development, if they can create a district in that part of the state and secure a joint supply, it can be made to serve not only as a supply for those cities but as a stand-by supply for the Metropolitan District to tide over a very dry year. You all know that when we say that the supply of the District is 155 000 000 gal. a day, we mean 155 000 000 gal. in a very dry year; that in nineteen out of twenty years we can get more than that,— just how much more depending largely upon the storage provided. If we have at hand a reservoir and a reserve supply which can tide us over this dry period, our present supplies will last just so much longer. And I believe we should study very seriously this Ipswich River problem in connection with the problem of the Metropolitan District. In fact, we have asked the Legislature for an appropriation to enable the State Department of Public Health to make such a study. This study was not made in any

detailed way in connection with the investigation which Mr. Goodnough has been telling us about.

My plan, therefore, based on the report of the Joint Board, would be first to build the Ware River tunnel; and, second, a little later, i.e. when necessary, to filter the South Sudbury and Cochituate supplies; third, to construct the Ipswich River development; and, fourth, at some later date to extend the Ware River tunnel to the Swift River and complete the development which Mr. Goodnough has described. Personally I doubt very much if we shall see that Swift River reservoir in operation within my own lifetime. It may be that it will be necessary, but that will depend upon the growth of the Metropolitan territory and on the feasibility of developing the Ipswich River and other eastern sources. Yet, as an engineering proposition, I believe in the Swift River project. I think it is an excellent one. I think that it will some day be needed and I even go so far as to say that it would be the part of wisdom for the State of Massachusetts to acquire — by right of eminent domain if necessary — the necessary sites for the dams and perhaps to go further than that and obtain by purchase from willing sellers such other land as may be necessary. I believe it would be good business on the part of the State to get some of those pieces of land, even though they may not be necessary to be used perhaps for twenty years or more.

Speaking of the Ipswich River, it may be said that another advantage of a great development there would be to help out the cities of the Merrimack valley. The Ipswich River water is now being taken up or asked for at the hands of the Legislature by various local communities. The Joint Board believes that it would be much better for these cities to pool their issues and develop a supply adequate for all. This Ipswich water would have to be filtered, of course.

Those of you who read the report of the Joint Board, which is now in press, and which will be issued before many weeks will be especially interested, I think, in two or three things which Mr. Goodnough has not mentioned. One of them is the general attitude of the state authorities towards the filtration of the surface water supplies in the state. We have unreservedly approved that policy. We believe that it is only a question of time when practically all of our surface waters will have to be filtered. Personally I believe that the time is not very far distant when the Metropolitan water will be filtered.

You will also be interested in the policy which has been set forth in regard to the use of great ponds. There have been some discussions in this Association, as you know, in regard to boating, fishing, and bathing in reservoirs. A policy has been defined. The Joint Board says, for example, that while from a health standpoint it is quite possible to safeguard the water consumer against infectious disease by filtration and disinfection, every community ought to have the right to say whether it wants to drink water which has been subjected to possible pollution and sub-

sequently purified. In other words, the sentimental objections ought to be considered, as well as the hygienic and economic phases of the problem.

I think you will also be interested in studying very carefully the very important point which Mr. Goodnough has brought up in regard to the use of flood flows. In some respects it is a different method of taking from what has been customary in the past. As you know, the courts in this country do not recognize what is called "compensation in kind." The principle appears to be a good one; it has been adopted already in some places by agreement between the mill owners and the water works authorities. I think that is a matter which this Association ought to discuss very carefully, — perhaps at some subsequent meeting. I mean the general relation between the use of water for power and the use of water for water supply purposes. Let us see if we cannot come to some friendly agreement between the mills who want water for power and the cities who want water for water supply purposes. Both are very desirable things and there ought to be some better way of solving those problems than by going to court every time we have a difference of opinion.

I am sure that you will all be interested in the report when you have an opportunity to read it, and I know that you will all appreciate Mr. Goodnough's paper, just as I have. (Applause.)

ADDITIONAL DISCUSSION OF WATER SUPPLY CONDITIONS AT SALEM, OHIO.

MR. H. F. DUNHAM.* The excellent paper of Mr. Dittoe read at the Bridgeport meeting and the interesting discussion following it brought to the surface two or three inquiries and comments that may be worthy of notice. The work described was carried out in a generation earlier than Mr. Dittoe's and in behalf of fairness and of the Chief Engineer of the Salem Water Company, Mr. E. C. Clarke, the writer begs the favor of a page in your JOURNAL.

The Salem Water Company purchased a small local water plant that obtained its supply from drilled wells almost in the center of the city. With this nucleus a franchise was obtained by Eastern parties who neglected or overlooked sundry facts relating to the difference between glacial drift deposits in Ohio and in New England. Despite protests relating to geology, the insistent demands of the city were finally complied with and a section in the franchise limited the supply to wells and springs. It was necessary to keep up the service from the old wells during the new construction. But at the same time, the weakness and danger in that source were recognized and a favorable area sought outside the city limits for a more abundant supply of softer water, the well water being very hard.

While the location for the new water works pumping station was not all that could be desired, it was fairly satisfactory for the important feature of direct fire protection. With an outside supply to keep the stored water level, at the station, above the surface of the ground as intended, there could be little danger of pollution. It may be noted that under the conditions incident to almost complete and continuous exhaustion of water from reservoirs and wells at that station, pollution was sought scientifically and not detected.

The works were built at the new location and a well drilled to a depth of six or seven hundred feet or down to near the "black shale" which is taken to be everywhere dry. Little water could be obtained. The old wells were connected to the new station by *wrought-iron* instead of cast-iron pipe under the comfortable impression that it would be needed for only a short time and could be more easily removed.

But when it came to an effort to secure a change in the terms of the franchise, complete failure resulted. Then the water company tried to secure a change in the Ohio code that would have removed a very serious handicap and enabled the company to first obtain a better supply and then

* Civil Engineer, New York.

treat with the city for a change in the franchise. At that time no water company in Ohio could exercise the right of eminent domain,— a right that might be about as necessary to a water company as is a charter to a railway company. Only two or three years previous to that time the legislature had passed such an enabling act but in its passage an amendment was introduced making an exception of cities having more than a certain number of inhabitants. This addition to the original bill annulled the whole act by making it "Special Legislation." Apparently it was a simple affair to petition again. One of Ohio's very able attorneys, the late Honorable William A. Lynch,* a leader in the political party then in control of the legislature, prepared and introduced the bill. At the writer's suggestion a clause made it impossible for any water company in that State to ever exercise the right of eminent domain unless all of its purposes and plans had been presented in careful detail to the Ohio State Board of Health and fully approved by that Board.† The Bill was endorsed by the Council of one Ohio city then supplied with water by a private water company. That city, however, was Massillon not Salem. *The Legislature turned down the bill in record time!*

There is an excuse for thus mentioning items from the past for they show the absence of that full coöperation between State and City authorities and private water companies which would have been so helpful in Ohio during that period. Experiences at Newark, Ohio, are readily recalled.

The writer is not familiar with the conditions under which the city of Salem acquired its water works property, but the authorities have been consistent in this, namely, they have continued to secure and accept a very scanty supply of hard water during a period of nearly forty years.

* Mr. Lynch was chairman of the Ohio delegations when Cleveland was nominated for presidency.

† The Bill had the approval and as far as possible the support of the Board. (H. F. D.)

ELECTRIFICATION OF GATE VALVES.

IMPORTANCE OF QUICK AND POSITIVE CONTROL IN PREVENTING PROPERTY LOSS BY FLOODING. HOW THE VALVE OPERATING SYSTEM WORKS.

BY PAYNE DEAN.*

[*December 14, 1921.*]

Electricity as applied to the operation and the control of large water works gate valves represents an engineering development of relatively recent origin. The remarkable success that has followed the installation of modern electrical equipment in various systems during the past few years has fully demonstrated the importance of valve control, not only as a labor saving means, but as a safe-guard against the hitherto enormous damage to property due to flooding from broken mains.

Within but a few years the electrical valve control system described herein has almost entirely superseded all other methods of power valve operation, including the hydraulic-cylinder type which had been in use to some extent in the past where conditions were favorable, and where remote control was not essential.

OPERATING LARGE GATE VALVES.

Large gate valves as a rule do not receive a great deal of attention once they have been installed, but after they have been in service for some years they become exceedingly difficult to operate. It is not unusual for the closing of a large valve to require the combined efforts of six or eight men. In view of the physical effort required it is easily understood why the valve is avoided, and in fact totally neglected in many instances. Under these circumstances, the condition of the valve gradually becomes worse, until when it is suddenly called upon in an emergency it is not fit for operation and hence impossible to close.

The water works superintendent is obviously aware of the condition of the valves and the more important valves in the system are almost always a source of considerable worry to him. The amount of time and labor required to manually test the valves is so great, however, that in many cases it is a practical impossibility for him to maintain the valves in thorough working condition without neglecting other important work.

Shut-offs take considerable time, and in the event of a break considerable damage may be done by an uninterrupted flow. To be able to close a pair of 36-in. or 48-in. gate valves in from 10 to 12 minutes would at least save a bad washout and considerable property damage. This can

* New York City. Member A.S.M.E. and A.I.E.E.

be accomplished from a convenient point and requires the attention of but one man who has merely to turn a small handwheel.

It is also possible to operate standpipe valves from a remote point. This is important in systems where it is required to pump high pressure directly into the mains. Pump discharge valves are electrically operated in many installations, allowing different pumps to be put into service without loss of time. When an electrically operated pump of the centri-

DEAN CONTROL. FLOOR STAND.

fugal type is shut down, the failure of the check valve to close would probably cause considerable damage. By applying electrical operation to the discharge valve adjacent the check, both the pump and the motor are afforded additional protection as well as greater flexibility of operation and control.

Undoubtedly one of the most important fields for electrical valve operation is in the protection against the serious consequences which might otherwise follow the breaking of large mains. A shut-off may be effectively made where the more important valves are under electrical control, and a portable automotive type of valve closing apparatus is maintained for use

in outlying districts. The portable valve closing apparatus is also useful for operating the numerous small valves of lesser importance and which may be situated at widely separated points.

Valve Control in Congested Districts.

There are certain extremely congested business centers in our large cities that would be subject to enormous loss and serious inconvenience if undermined and flooded. Public buildings, such as art museums and

Two 48-in. Electrically Operated Valves in Vault.

libraries housing valuable works of art, would be in serious danger if large volumes of water penetrated through their foundations. Underground railways are especially susceptible to water damage, and while the third rail and other electrical equipment is submerged the system is inoperative.

There are innumerable reasons why consideration should be given to the subject of protection against damage from broken water mains, and it is interesting to know that municipal authorities are beginning to more fully appreciate the savings which may be effected by the installation of suitable valve operating equipment.

Electrical Systems Most Efficient.

Until numerous installations had been made and actually operated over a period of time, there was considerable doubt in the minds of superintendents and others as to the reliability of electrically controlled valves. It is now, however, an established fact that a few well placed electrically operated and controlled valves will afford ample protection for any congested district. Further, it has been shown that electricity affords the only system adopted to meet all of the varying conditions under which valves must operate. Electricity is the most reliable source of power known and is now almost universally available.

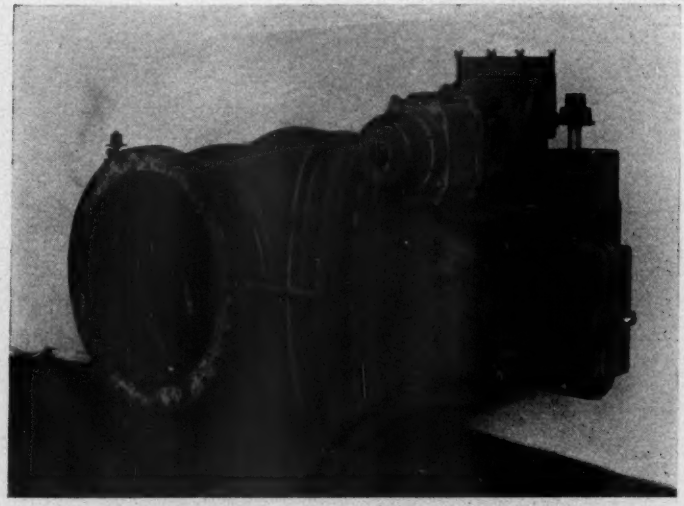
Mechanical Position Indicator.

The design and construction of the electric motor has been carried to a high degree of perfection and dependability. It is available for almost any use and can be made water-tight and able to withstand operation in the open exposed to snow and ice, and even while under water. Obviously the control apparatus can be ruggedly constructed and inclosed in a moisture and fool-proof casing so that a complete system may be built up, all of the operating parts of which are fully protected against outside influences.

By the employment of lead and steel covered cable, the conductors may be laid in an open trench.

Valve Operating Apparatus.

The large valves in street vaults present a number of difficulties for the following reasons. Frequently the valve is very old, corroded and difficult to operate. It is required to be closed against velocity due to break in the line. The control apparatus must be of such a size and nature as to pass through the ordinary man hole. Space is limited in the vault, making it imperative that the installation be made with as little labor as possible. The apparatus must of course be absolutely water and damp



30-in. Inside Screw Valve Fitted with Dean Control.

proof, and should not be affected by water that may collect in the vault. Also standing idle for long periods must not affect the operativeness of the system. The equipment must be self-contained, self-lubricating and unaffected by extremes of temperature. For the protection of the valve the mechanism must be provided with means positively operating to stop the gate at each extreme of its travel.

Dean Control System.

This system has been especially developed for the electrical operation of valves and incorporates all of the essentials which long experience has shown to be necessary for these valves. It is the only complete system of valve control that has been devised, and hundreds of installations in various kinds of service are in satisfactory operation throughout the country.

There are five important characteristics of the Dean System —

1 —It is a single standardized unit.
2 —The unit may be attached to existing valves with a minimum of effort and without shutting down the line.
3 —Operation is positive and accurate, and does not depend upon the momentum or drift of the moving parts to seat the valve.
4 — The motor exerts a high initial torque and affords a sufficient reserve of power for operating the valve under various conditions of velocity and pressure.
5 —The complete system is totally inclosed and water-proof.

The Dean Unit embraces the driving motor, reduction gears, and limit trip mechanism all inclosed in a standardized moisture-proof casing. The units are built in a series of types embracing the complete range of valve sizes. Each unit is equipped with feet provided with four bolt holes for attachment to the valve.

ELECTRICALLY OPERATED VALVE MANHOLE COVER CONSTRUCTION.

INDICATING DEVICES FOR VALVES.

For showing the position of the valve gate two types of indicators are employed. At the valve a mechanical indicator is installed which shows upon a dial how many turns have been made in opening the valve so that danger of jamming the valve parts is eliminated.

Where it is desired to operate the valve from a distant point an electrical indicating system is employed so that an operator at the remote station can note the position of the gate from a conveniently placed dial. In both of these systems the mechanism is thoroughly protected from moisture and dust by a suitable casing.

Dean Unit.

The motor of the Dean Unit is completely inclosed and water-proof and develops an extremely high torque. The normal speed is 2 400 R.P.M., and through a system of worm and planetary gearing the slow speed shaft which drives the valve stem rotates at approximately 50 R.P.M. The motor and worm shaft are ball bearing and the gearing runs in oil.

The system is furnished for 220 volts, 25, 40 or 60 cycles, single phase A.C., or 110 or 220 volts D.C.

The valves may be controlled from one or more local or remote points, the control stations being provided with red and green indicating lamps showing the position of the valve. The system is applicable to any existing valves whether of the O.S. & Y., or I.S. types without shutting down the line and the valve may be operated manually if the current fails.

Discussion.

Mr. J. E. Garrett.* On the question of a unit which can be operated electrically and also by hand, is it necessary to turn the motor of the electrical control in operating it by hands?

Mr. Dean. There is a clutch that you have to pull out by turning three times around the screw. That declutches it. Ours has a worm drive; and turning the worm, a reversible worm, is quite hard; but even a worm will turn. But, preferably, you have to unclutch to do it. That is the best way.

Mr. Garrett. And when you couple it up again, you automatically put it back?

Mr. Dean. You have to put it back manually. If you do not put it back when you have finished operating by hand, we have indicating lights in the control station and the light shows that it is open. The red light comes up and shows you that there is something wrong in the system.

Mr. Garrett. There is the possibility of getting into trouble if you have hand operated and electrically operated combined?

Mr. Dean. You have to have hand operated and electrically operated combined. The thing to do is to get a safety device to show you that you are not in mesh, as it were, before you start operating by power.

Mr. Garrett. You can't put it back in mesh wrongly, then?

Mr. Dean. No. You only have to turn a handle. But that has been one source of trouble to every operating force in the water works departments, through their overlooking those fine features.

Mr. E. A. Hancock. How accessible is the control for repairs?

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* Civil Engineer, Hartford, Conn.

MR. DEAN. It is as accessible as a piece of machinery of that kind can be made. In putting the covers on the vaults, we have them large enought to allow handling the machine. The vault is the worst thing in the world to make repairs in. Of course the atmosphere in a vault is of high humidity and it is difficult to keep it absolutely dry. But we need to go to the extent of keeping all the electrical contacts so that they will operate when we put the juice through them. Our difficulty is principally in constructing a device that is fool-proof, and which can be put into anybody's hands, and I don't know yet whether or not we have succeeded. We are keeping an eye on all we have out.

MR. HANCOCK. Is that furnished for all electrical power?

MR. DEAN. All circuits up to 220 volts. We have stipulated a maximum voltage of 220, because of the inadvisability of putting higher voltage on a small motor. Another thing you want to bear in mind in operating the valve is this: The high strains put on at the time of winding represent the maximum strain that should be put on the windings of the machine, because you do not have any resistance to check the current down.

PRESIDENT SHERMAN. Have you had any trouble with the electric welding of old yokes?

MR. DEAN. We take the yoke out when we can. When the superintendent is not looking we sneak the yoke out. I had a superintendent from Cambridge call me up this morning. My man went away and left some of the yokes off his valves. The man who did it is in Philadelphia. He says he can't operate the valves. We will take the yoke off and weld it and get it back quickly.

PRESIDENT SHERMAN. You find those welds stand up in good shape?

MR. DEAN. Splendidly. They are electrically welded. Sometimes we use thermite, and there is a tremendous strain on that yoke when we test it. There is a strain of some 8 000 foot pounds on the valve stem, and we have found it operates easily enough.

PRESIDENT SHERMAN. Do you have a uniform operating speed throughout?

MR. DEAN. No; the motor is wound and the unit is wound with particular reference to the necessity of shutting the line down, first fast and then slowly. You will notice when a crane pulls out a 10-ton load it goes very, very slowly, of necessity; but when it pulls out a 1-ton load it goes very fast. In shutting down the gate you can go $\frac{5}{8}$ of the way very fast, 12 inches a minute; but when you get to throttling water at high velocity you have to slow down, and the motor slows down until it gets almost to a stop.

PRESIDENT SHERMAN. It slows down sufficiently so that there is no danger of water hammer?

MR. DEAN. I might say that after experimenting and getting the advice of our engineers we have decided on closing mains under all con-

ditions at 3 inches a minute, and no faster. That is what we advise right through. I do not think you will get any water hammer then, at 3 inches a minute. And we gear to suit that. That is what we have been able to find, and that is what the engineers think about right.

MR. GARRETT. What distance from the valve is it economical to operate with a single unit without a relay conduit?

MR. DEAN. About 500 feet. Beyond that distance your copper becomes excessive and you best buy small copper wire and put a relay in.

MR. GARRETT. Beyond 500 feet?

MR. DEAN. Beyond 500 to 700 feet, depending on the size of valve and current required. A large valve takes 120 volts; that is 25 kilowatts.

MR. GARRETT. If at one station the valve is partly opened and left in that position, can the other station close it?

MR. DEAN. Each station has complete control over the valve.

MR. GARRETT. And the indicator in the other station will show what has been done?

MR. DEAN. The lights will show it.

MR. D. L. FURNESS. When you have operated a valve by hand and want to put it back, do you have to put the motor back in the position where you operated it by hand?

MR. DEAN. Oh, no; leave it where it is. In the new units, we are bringing out, the operation will be entirely automatic. That is a matter of evolution in the device we are getting out. I might mention one test that is costing probably $15 000. We have had great difficulty in shutting off high pressure steam in case the line breaks. The ordinary velocity on a steam line going to a turbine has a maximum of 5 000 ft. a minute. If the line breaks that velocity is apt to go up to 50 000 ft. or more. The engineers have put an electrically operated valve in to shut that down. We are having a test where there is 40 000 h.p. of steam available. We are given a 22-in. header and a 10-in. header going to these 40 000 h.p. boilers. There are eight different valves on the header, an English valve, a German valve and several American valves to keep that tight, —that test being carried out under my jurisdiction by the National Electric Light Society, in New York.

SOME OBSERVATIONS ON WATER CONSUMPTION.

BY CHARLES W. SHERMAN.*

[*Presented January 12, 1922.*]

The object of this paper is to bring to your attention some of the things we do not know about water consumption, and especially about what constitutes a reasonable water consumption, rather than to submit any new facts or to draw conclusions from existing data.

Everyone knows that what may be reasonable consumption in one city would represent extreme wastefulness in another, and that local conditions have great effect upon legitimate water consumption. This statement is, however, of little aid in attempting to reach a conclusion as to what is a reasonable consumption for any given case.

It is natural to expect that in the available literature upon water supply, a fair amount of information upon this subject may be had, and that it should be possible with the assistance of various books and publications to obtain sufficient data upon which to base a reasonable conclusion.

To test this assumption let us try the principal sources of such information.

Turning first to the "Water Works Hand Book," compiled by Flinn, Weston and Bogert, 1916, we find (page 545) a chapter entitled "Water Consumption." This chapter begins as follows:

> "*Per Capita Consumption* in U. S. cities and towns ranges approximately from 50 to 400 g.p.d. For communities having service connections wholly or largely metered, it is commonly under 100 g.p.d. and for small cities and towns often much less. For large cities with few meters, but well managed works in good condition, 125 to 150 g.p.d. is a reasonable allowance. Character of industries, climate, and other local conditions have important influences."

The remainder of the chapter is given up to figures upon quantities of water required for irrigation and discharged by lawn sprinklers, and a table upon water consumption in foreign cities. On page 414, however (in a chapter upon distribution systems), we find a table giving the consumption of water for the year 1906 in 19 American cities and towns, which are stated to be well metered. No other significant information upon what constitutes reasonable consumption is to be found in this book.

Referring next to the American Civil Engineers' Hand Book, 4th Edition, 1920, somewhat more and better information may be obtained,

* President New England Water Works Association 1921.

a table giving the consumption in 30 American cities, usually for the year 1917; but there is no information upon which to base a conclusion as to what constitutes reasonable consumption, or upon changes that should be expected with lapse of time.

Failing to find the desired information in recent books, let us try Fanning's "Treatise on Water Supply Engineering," published in 1877. On page 37, Fanning says:

"*Water Supplied to American Cities.* The limited use of water for domestic purposes in many of the European cities during the last half century, led the engineers who constructed the pioneer water works of some of the American States to believe that 30 gallons of water per capita daily would be an ample allowance here; and in their day there was scarce a precedent to lead them to anticipate the present large consumption of water for lawn and street sprinkling by hand-hose, or for waste to prevent freezing in our Northern cities.

"The following tables will show that this early estimated demand for water has been doubled, trebled and in some instances even quadrupled; and this considerable excess, to which there are few exceptions, has been the cause of much annoyance and anxiety."

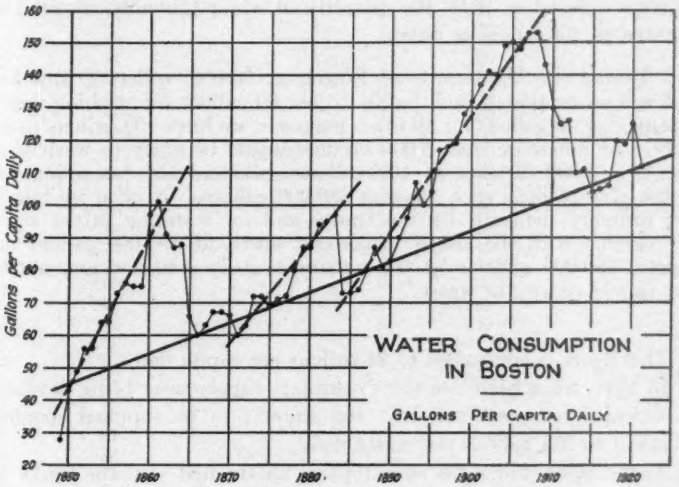
Following this statement is a table of consumption for the year 1870 in 23 American cities, another table showing comparisons between the consumption of 1870 and 1874 in 17 cities, and a third table showing progressive increase in per capita consumption in 13 cities from 1856 to 1874. Fanning states that "the legitimate use of water is steadily increasing," and that owing to the greater variety of purposes for which water is required in larger cities, a greater per capita consumption should be expected in such places.

"In the New England towns and cities, the average daily consumption and waste of water according to population is approximately as follows:

Places of 10 000	population		35–45	gallons	per cap.
20 000	"		40–50	"	" "
30 000	"		45–65	"	" "
50 000	"		55–75	"	" "
75 000	"	and upwards,	60–100	"	" "

In the files of the JOURNAL OF THE NEW ENGLAND WATER WORKS ASSOCIATION, we find the report of a committee presented March 12, 1931, which contains a vast amount of valuable information, more especially upon the quantities of water required for different classes of service or consumed in various cities at that time, together with some information upon variations in consumption over a limited period of years for a comparatively small number of cities. This information is of much significance, yet very little assistance can be derived from the statistics given in attempting to decide what changes are likely to occur as time goes on.

Turning back to an earlier date, we find a report by Dexter Brackett, on the consumption of water in the Metropolitan Water District in Vol. XVIII for the year 1904. This report, which was drawn upon freely by the committee previously mentioned, contains much of value, but has to do more particularly with the need for metering water in the Metropolitan District as a method of restricting waste. A considerable amount of helpful information may also be found in *Transactians, American Society of Civil Engineers,* Vol. XLVI (1901) p. 407, reporting an informal discussion upon " The Consumption and Waste of Water."



In Appendix II to the report of the Massachusetts State Board of Health upon " A Metropolitan Water Supply," 1895, Mr. Brackett discussed the present and future consumption of water in the Metropolitan District, and this report contains the most complete discussion of changes in consumption as well as reasonable use of any which has come to my attention, not excepting the valuable reports upon the additional water supply of New York. Changes in per capita consumption from 1850 to 1893 are shown for 17 American cities.

Mr. Brackett called attention to the necessity, in estimating consumption for future years, of giving consideration to the great increase in the number of water fixtures and also to the effect of increased pressure in causing greater use and waste of water.

The actual experience of the City of Boston, including the data upon which Mr. Brackett's studies were based, with the figures brought down

to the present time, furnishes a striking illustration of variations in consumption from time to time. The table submitted herewith shows the per capita consumption of Boston from the construction of the Cochituate works in 1849, to 1921. With the exception of the period 1908–1915 inclusive, during which a reduction in consumption was accomplished by the extension of the use of service meters, a general increase is to be noted, excepting only periods when the consumption was limited on account of shortage of the supply, and the period following 1883 when waste was controlled to some extent by the use of the Deacon meters.

It is interesting to note that when a water supply for Boston was first contemplated in 1825, the quantity of water probably required was estimated on the following basis:

"Taking the inhabitants of Boston at 50 000, collected into 8 000 families, and supposing each family to use 60 gallons for washing, and on the same day 40 gallons for all other purposes, we have 100 gallons to each family. As not more than 6 000 families would be likely to wash on the same day, 6 000 families at 100 gallons each and the remaining 2 000 families at 40 gallons each, making 680 000 gallons. Now, if we take the other ordinary demands by the trades and for watering cattle, streets, etc., together with the loss by leaks and waste, at 500 000 gallons more we get 1 180 000 gallons, as the maximum daily consumption, allowing every family to use the water."

This figure is equivalent to 24 gallons per capita daily.

In 1844, when plans for the Cochituate supply were being developed, the commissioners reported that the amount to be supplied should be equivalent to 28½ gallons per capita daily.

As the table shows, the consumption for the first year the works were in operation (1849) was 28 gallons per capita for the entire population. The commissioners probably felt their forecast was justified. This increased very rapidly, however, to 73 gallons per capita in 1856, and 101 gallons in 1861.

WATER CONSUMPTION OF BOSTON, MASS.
In gallons per capita daily.

Year	Consumption.	Remarks.	Year.	Consumption.	Remarks.
1849	28		1890	83	
1850	43		1	90	
1	49		2	96	
2	56		3	107	
3	56		4	100	
4	64		5	104	
5	64		6	117	
6	73		7	118	
7	76		8	119	
8	75		9	128	
9	75		1900	132	
1860	97		1	137	
1	101		2	141	
2	91		3	140	
3	87		4	149	
4	88		5	150	
5	66		6	148	
6	60		7	153	
7	63		8	153	Metering law
8	67	Supply	9	143	
9	67	inadequate	1910	130	
1870	66		1	125	
1	60		2	126	
2	63		3	110	
3	72		4	111	
4	72		5	104	
5	69		6	105	
6	71		7	106	
7	72		8	120	
8	80		9	119	
9	87		1920	125	
1880	87		1921	112	Pitometer surveys
1	94				
2	95				
3	97				
4	73	Deacon			
5	73	meter			
6	74	work			
7	80				
8	87				
9	81				

Note: Records for 1849 to 1893 are for the Cochituate works only; the remainder are for the entire city. The figures for the years 1898 to 1903 have been estimated from those of the Metropolitan District.

Doubtless a portion of the increase was due, as is always the case with a new water system, to the fact that at the beginning a comparatively small portion of the population was actually served, and figures of per capita consumption based upon the total population would accordingly give too low a result. It is undoubtedly the fact, however, that the greater portion of the increase was due to waste and leakage.

It is interesting to note the figures which competent engineers estimated at later dates as representing reasonable and proper consumption for Boston. In 1873, Joseph P. Davis, in reporting upon "An Additional Supply of Water," stated:

"The average daily consumption per inhabitant has varied during the past few years between wide limits, having been ninety to one hundred gallons as a maximum, and somewhat less than sixty as a minimum.

"As the new area to be provided for will undoubtedly contain a less proportion of manufacturing and shipping interests than that now supplied, and as there will probably be means devised at no distant day to check the great waste that has heretofore taken place, an allowance of sixty gallons for each person should, and without much doubt will, be ample."

City Engineer William Jackson in a report upon "The Water Supply of Boston," dated 1886, said:

"*The Proper Allowance per Head of Population.* — As is shown by the opinions of engineers, quoted by Mr. Crafts, the proper allowance per head of population varies largely, and the earlier estimates were much smaller than those of recent years, and also much smaller than the experience of any American cities will at present warrant.

Since the construction of the Cochituate works, in 1848, the facilities for the use of water as well as the uses to which it has been put have been constantly increasing not only here but throughout the world.

In 1857 there were 48 000 house water fixtures connected with 20 000 services in the city of Boston; in 1885 there were 188 000 fixtures supplied from 52 000 services. In other words, the number of fixtures per service had increased in twenty-eight years from $2\frac{1}{2}$ to $5\frac{1}{2}$.

* * *

"That a certain portion of the water supplied in Boston is wasted, and that the present consumption per capita can be reduced to some extent, is not disputed; but in view of the previously stated fact that the efforts of the past three or four years have not reduced the consumption below 70 gallons per head, it is not deemed safe or advisable to use a less amount in considering the future requirements of the city."

In his 1895 report cited above, Mr. Brackett does not give an estimate of the reasonable consumption of Boston, but states that in estimating the requirements of the entire Metropolitan District for the succeeding 30 years, a consumption of 100 gallons per capita daily should be assumed. This may probably be assumed as equivalent to about 120 gal. per day for Boston.

In the report of 1903, his estimate was that *if waste were not prevented*, the per capita consumption of the District should be expected to increase from 134 gal. per day in 1910 to 174 gal. in 1930, (corresponding roughly to 160 and 205 gal. per day for Boston); and that if waste were prevented, the corresponding figures would be 80 and 100 gal. per day for the District (95 and 120 gal. for Boston). For 1920, his figure would have been 154 gal. per day for the District if waste were not checked, and 90 gal. if waste were prevented (180 and 105 gal. for Boston).

The experience of Boston has been cited as more or less typical of that in the larger American cities, and indicates how difficult it is to draw a fair conclusion upon reasonable consumption at the present time, much more so for a future period. In view of the present conditions in Massachusetts with the probable need for an early extension of the water supplies of some of our important cities, it is a subject to which serious consideration must be given and upon which it is most important that sound conclusions be reached if proper provision for the future is to be made.

TOPICAL DISCUSSION: CAN HIGH-VALUE WATERSHED LANDS BE PUT TO PROFITABLE USE?

[*September 15, 1921.*]

MR. SAMUEL P. SENIOR.* Mr. President and Gentlemen: Some time ago Mr. Sherman came to Bridgeport and asked me to write a paper about Bridgeport's water supply. I told him I would do it. And I also told him that I would like to ask a question about watershed lands.

The problem I want to ask about is this — by the way, I have never heard it discussed or seen a reference to it in any of the publications of the various engineering societies. In the case of rough and rather cheap lands it is customary, I believe, for water companies to plant conifers, such as white pine, red pine, and so forth, and get some return in that way. But the thing I want to know about is regarding land of better character and higher value. For instance, we have perhaps 1 000 or 1 500 acres of land that is valued at $200 or $250 an acre. Manifestly you could not expect to get a return from land of that value by planting pines or other conifers.

The question is, What are you going to do with that land? If you allow it to take care of itself in a few years it will grow up to white birches, briers, and so forth, and your land which cost $200 an acre will be worth, perhaps, $25 or $30. So that the problem is to keep that land up to its initial value.

I would like to know what the various members do with land of that kind. We have an agricultural account which, I think, runs up to about $90 000 a year for work of this kind. We have tried potatoes and corn, and other forms of crops, but the difficulty is right here, in my opinion: a farmer can live and make a living from such land in this locality where he keeps cows in connection with the farm work. He can with the same amount of labor keep 12 to 15 cows, and from them get a daily income, and in addition to that get fertilizer that he uses to take care of his crops. We failed to show a profit on potatoes, corn, and similar crops. In fact, found that we worked at a loss, and for that reason.

At the present time most of our land we are getting into grass and sell a great deal of standing hay. We also cut a lot of it, bale it and sell it at the best price we can get. The idea of getting it into grass is that less labor is required on land so planted than anything we know about.

We also are experimenting with orchards. There are about 100 acres now planted to standard apples, and in many cases peaches are grown in between the apples and we have marketed some peaches. We have some

* President Bridgeport Hydraulic Company.

apple trees that are nearly old enough to bear. As you know it takes about eight years to get a crop of apples.

MR. J. W. DIVEN.* The main, if not the sole object and reason for purchasing watershed lands, is to protect and improve it as gathering ground for the water supply, not to make profit. If the land is to be used or leased for ordinary farming purposes then why buy it? Unquestionably forestation is the best way to use such lands, the way that will most improve them as gathering grounds and that will most improve the water supply from them. Cropping them, using them as pasture lands, cultivating them will not improve the quality of the water gathered on them, in fact will leave them about as they were under individual ownership.

But if not satisfied with the slow asset of timber raising, or if the land is not suitable for that purpose or is considered too valuable, then the consideration becomes what can be raised on it that will have the least injurious effect on the water supply. This will depend largely on the character of the soil. But it should be always borne in mind that the least the land is "worked" — plowed, cultivated or in any way broken up — the better. Plowed land will, with heavy rains, wash into the streams, reservoirs, etc., making the water turbid, as well as carrying with it many impurities and injurious substances. If the land is suitable for hay,—and most of our northern hill lands are — that will be among the most suitable crops for watershed lands. On the ordinary hill soils hay crops will run from four to six years without reseeding, possibly with proper care, late fall and early spring seeding on the sod, it will run much longer. Alfalfa, if the soil is suitable, would be a better crop, as it stands longer, and its tough and deep roots would best prevent gullying and washing of the land. Either are profitable crops and require little working. With the modern farming machinery, tractor propelled, it would not even be necessary to go on the land with horses, thereby eliminating one possible source of contamination of the supply.

Fruit orchards or nut groves would entice the small boy to trespass, and surely the fewer people permitted on the watershed the better, for any one might be a typhoid carrier and cause serious contamination, resulting possibly in an epidemic. Fruit orchards to be properly cared for and protected would mean the dwelling on the land of many people, always a source of danger. Orchards require considerable care, the using of chemicals that would not be considered pleasant in drinking water, among other things, and they surely require close watching if the owners are to reap any benefit or profit from them. Nut trees require little care, but do need guarding, and in places remote from residences are considered by the small boy as common property.

It may be argued that leased lands can be better controlled than privately owned, that proper restrictions and regulations can be made. The speaker's experience is that the restrictions are hard and costly to

* Secretary American Water Works Association.

enforce, the lessee naturally wants to get all he can from the land, and, unless his lease is to be a long one, apt to get from the land all he can, putting as little as possible into it, so that the land would soon be exhausted, worked out and unfit for farm land. Perhaps this would be a good, as well as a logical, solution of the problem, as there would be no high value land to be considered and forestation would be the final outcome, and the best watershed protection be accomplished.

MR. ALLEN HAZEN.* But little of the land acquired for water works purposes in New England and the adjoining states has been sufficiently valuable to make this question important. Ordinarily devoting the land to forestry seems to be the best solution. There are, however, places where much more valuable agricultural land has been taken for water supply purposes. In California some very valuable land has been so taken.

The Spring Valley Water Company, supplying San Francisco, has perhaps the largest holdings. It owns about 100 000 acres of land. This includes several million dollars worth of very productive land. The company is not able to operate that land directly at a profit, but what it has done has been to organize an agricultural department with a very competent superintendent who finds out what each parcel of land is fitted for, and can be used for without injury to the water supply and then leases that parcel, restricting its uses to these purposes that he has decided upon. The leases provide strictly what tenants can and cannot do, and they contain all the provisions which are thought to be necessary to protect the water from pollution. These conditions vary according to how the land is located. Some of it where the conditions make it suitable, is used for general agricultural purposes and is cultivated and cattle kept upon it. In other locations closer lines are drawn. Areas about reservoirs may not be ploughed and cultivated, but they have been leased for grazing purposes. Sheep are found to be cleaner than cattle, and sheep have been permitted in certain places where cattle would have been regarded as objectionable.

The agricultural operations of the company have resulted in substantial net profits, running up to something approximating $200 000 per annum and this is quite an important aid to the company in carrying these valuable lands that are necessary for protecting the quality of the water supply. From an accounting standpoint there are some practical difficulties. As you know the state supervision of public utilities of California is very close and the state officers find it difficult to satisfactorily audit these agricultural accounts. One way out of the difficulty that has been talked of but not yet adopted, would be to form a subsidiary land company making a contract with the water company for the management of lands and completely separating the accounts from those of the water company.

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* Consulting Engineer, New York.

MR. WILLIAM A. MACKENZIE.* I have not had personal experience along the line of utilizing the higher priced land in the watersheds of public water supplies. Wallingford has had success planting Norway and Scotch pines, but I can not predict how it will turn out from a financial standpoint.

However in my section there are a large number of apple and peach orchards. These lands on the rolling hills have been bought for a nominal price and then by planting apple and peach trees in alternate rows they have yielded a good profit within a few years.

I have in mind one farm in particular where I do not think the present owner paid over $5 000 for an 80 acre-farm. The apple trees have been bearing about four years and this year his entire crop of peaches and apples was worth about $45 000, and he was offered $100 000 for the property with this year's crop. But the owner stated that his lowest price was $125 000. The owner is not a farmer and does not live at the farm or keep any stock on the premises.

I believe high-priced sections of watershed lands can be set out to apple trees and with expert care show a profit within a reasonable length of time.

MR. J. E. GARRATT.† The experiences that we have had at Hartford may be of some interest. The lands that Hartford bought for its new water supply were of many kinds, of course, and amongst those lands were orchards that perhaps would not run as the best quality, but they were orchards that bore fruit. Our experience has been that the best proposition is to cut those orchards down and get rid of them because of the fact that to care for the fruit and to get it for our own use would require such a guard that it would hardly pay to save that fruit. I wonder if you did go into the fruit business whether you would be able to save it for yourself, or whether, as water-works lands are located, being separated from the populated districts, the fruit would be taken care of by others.

MR. THEODORE L. BRISTOL.‡ Our problem is considerably, I think, like Mr. Senior's. We tried everything to get some revenue from our lands. We first started in setting out some pasture land to chestnut, planting the nuts themselves, and then installed a nursery and planted seedling chestnuts from the nursery. Of course, most of those are gone. Then we tried white pine, and some of the stock came from Germany and was infected, and a good deal of that has gone. Now we are planting red pine.

Then we tried chemical fertilizing and green manuring. No stock was kept on this property, so tried green manuring by ploughing under rye. That was a failure, — I think perhaps because we did not understand how, although we had a farmer in charge.

Then we tried sheep and started in with a man who knew his business. The highest number of sheep was 400 and when we got through

* City Engineer and Superintendent Water Works, Wallingford, Conn.
† Civil Engineer, Hartford, Conn.
‡ President Ansonia, Conn., Water Company.

we were $3 500 out of pocket, and hadn't any sheep. At the present time we are trying to keep the land that is not too poor in grass, but hardly get our money back for taking care of it and keeping it up, re-seeding, and trying to make grass land out of it. We have tried alfalfa, that was not a success.

MR. DIVEN. You did not try it right; you forgot the lime.

MR. BRISTOL. No; we bought carloads of lime, — a great many carloads of lime — and have used fertilizer. You have to treat the soil with bacteria. I do not think there is a speck of that alfalfa left. We had a fair stand to start with, but the second year there was none left, having been winter-killed.

Now I think our principal revenue is from cider apples. The only way I can see that we can make any money on cider apples is to sell somebody the output of the orchard and let them watch it, because we could never keep any apples on the orchard ourselves. I think if we told somebody that they could have those apples at a certain price, they would watch the orchard to see that nobody got them.

MR. HUGH MCLEAN.* It is a question in my mind whether or not we are putting our efforts to any good purpose when we are trying to do something with our farm lands. We have got about 3 500 acres. We have gradually been accumulating farm after farm. But it does seem that there should be some power somewhere that would compel the water commissioners to put that land to some use. We have taken it away from productive possibilities. We buy a 200-acre farm, which was formerly capable of taking care of 35 or 40 head of cattle and raising crops, and it is abandoned. The buildings are taken down and everything goes to seed. Whether it is in the form of reforestation, or whether it is in the form of fruit trees, or grass and hay in some form, it seems to me that there should be something worked out through our agricultural colleges, which we maintain by taxation so that we will have some service rendered and advice given us as to what it is best to do.

Two years ago, having that in mind, we set out about 500 000 pine trees on our watershed. Now, is it going to be profitable? Some people say that we can sell them for a million dollars in thirty years; and if in thirty years time they are worth a million dollars, we have done the public a good service.

Is there any other tree that might be set out? For instance, the black walnut? I understand that the black walnut of the country is about gone. It might be possible to set out forests of black walnut if the lands are adapted to them. We ought to clean up the forests, and set out something that will pay.

We have had quite a good many fruit trees on our land, but they have grown old and are not profitable, so we decided to cut them down and

* Water Commissioner, Holyoke, Mass.

set out something that would be profitable. I think the pine trees will preserve the purity of the watershed, and will bring us a harvest in time unless a fire gets into them. I think we ought to be compelled to do something by the state.

MR. M. N. BAKER.* As a general proposition I should suppose that there would be no question but that forestry work, even for relatively high-priced lands, might in the long run be the best thing. It has been common in Europe, as many of you know, for generations, and in some cases for centuries past, for cities to maintain municipal forests. If this matter were taken up in a broad-minded and scientific way with proper coöperation, it seems to me that forestry, in the long run, would be found to pay. We certainly have got to do something in this country to provide for the future timber supply. I know by my own experience that so far as any immediate returns are concerned, it is entirely out of the question for a private individual to replenish denuded lands by planting forest trees. I planted some 50 000 trees (cuttings and transplants) on an Adirondack farm that I sold recently. I did it for amusement and for the pleasure of seeing them grow, and I feel I got my money back from that viewpoint, but of course only my children would have reaped any direct profit from these plantations, had I retained the land, unless I should have been so fortunate as to live and retain my faculties to a ripe old age. Doubtless, I sold the farm to better advantage because a considerable part of it had been reforested.

I believe the Massachusetts forestry tables are the ones generally cited in this country as to the possibility of revenue. They show a slight return from white pine, after only some twenty-five years. The white pine experience has been somewhat disastrous on account of the blight, and attention now is being given to planting other species of pine. I found in my own experience that for immediate results the Scotch pine was very much better than the white pine in the Adirondacks. (I never had any trouble with blister or any other disease.) The Scotch pine takes hold much more quickly and makes much more rapid growth than the white pine. When it becomes marketable it will not be worth as much as the white pine, however, and that has to be taken into consideration.

Reforestation must be regarded as a long range proposition, and it should be taken up in a very broad way. In a number of states there is no difficulty whatever for a city or private water company to get all the coöperation that they may reasonably desire from the state in which they are located. In New York and in Pennsylvania, — and I dare say the same is true in other states, but it is conspicuously notable in those two states — an immense number of young trees have been set out on water works drainage areas.

* Associate Editor, *Engineering News Record*, New York.

MR. X. H. GOODNOUGH.* I believe the planting of forest trees on watersheds is becoming quite common in Massachusetts from what I have learned from the State Forester and elsewhere. Many of the cities have purchased forest trees and are beginning forestry on their water supply watersheds.

As to profit from forestry, I think that the Forestry Department published some years ago a statement in which they said that after 25 years a little income might be obtained but that in 30 or 35 years the income would be a better one and eventually, on the basis of the recent price of pine, they believe that an income of $7 an acre can be obtained from the pine lands. That would be all profit, as I understand it.

The planting of forests is about the best method of utilizing the watersheds of public water supplies, as I see them in Massachusetts. Most of these watersheds are rough lands not adapted to general farming and forestry is handled very well on some of those watersheds.

The Agricultural Department appears to think that such lands can be used for grazing. The land varies greatly of course as to the number of animals it will support. Some pasture land will support quite a number of sheep per acre — something like 5 to 7 — but it appears that such a number of sheep would require better than the average pasture land so that it is safer to estimate on 5 or 7 sheep on 2 acres of the kind of pasture land that is ordinarily met with in the various watersheds.

Orcharding could not be handled as a rule by municipal authorities, and in order to handle it properly of course it has to be dealt with by long leases. I do not know of any place in Massachusetts where orcharding has been tried, but I think the general feeling is now that the pine crop is something that is worth trying, and has so far been pretty successful. There has been no very great loss as yet from fires. There was one large fire in New Bedford several years ago, but other than that I have not heard of any large losses from fires in pine lands within water supply watersheds.

MR. RUDOLPH HERING.† It seems to me when we are making such improvements in the purification of water that it may not be very far distant when we shall purify all surface water and give up the possession of watershed lands from which we expect to get fairly pure water. Therefore, I am somewhat in doubt about how to answer Mr. Senior's question. It depends a good deal on how much we can absolutely guarantee in the way of purifying water from small, as we do now from large, streams, where the cities do not own any territory at all but rely entirely upon the purification of the water. Now, if we can filter and purify the water satisfactorily from the smaller areas, in time we shall not be required to possess large areas of watershed land where the difficulties that have just been mentioned by the speakers will arise.

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* Chief Engineer, Mass. State Dept. of Public Health.
† Consulting Engineer New York.

MR. BRISTOL. I would like to ask if anybody has leased the berry privilege on their lands. We have a lot of berry pickers that get a lot of revenue from our land.

MR. DIVEN. Keep the berry pickers off.

MR. BRISTOL. It is some job.

MR. WILLIAM J. WILLSON.* I would like to ask Mr. Senior regarding the care of these trees,—whether the underbrush is cut down and some expense incurred in caring for the trees, or are they allowed to grow without care?

MR. SENIOR. We usually clear the land the year before we plant it, and then I think you would have to clear the brush overhead about twice before the trees got big enough to take care of themselves. Clear the land where the trees are planted and then in a few years you will find that they are being over-topped because they have not sufficient start to get ahead of the underbrush; and a few years later it is quite likely you would have to cut it out again. We have been having trouble with just that thing this summer, and it is a question whether it pays in some cases. The underbrush gets a start, and it costs a lot of money to cut it out. In some cases we have actually left it and let it drive the pines out, because the cost was prohibitive. To raise the conifers to commercial size is a difficult thing, and it is a question in my mind whether it ever pays, even in rough lands, because of some of those practical costs.

Another thing is fire. You lose a lot of them through fire. Those of you who have had to clean up brush land for your reservoirs know that the cost is a very real item. If the brush gets in there it will crush your pines down when you go to cut them. And it costs too much to handle the wood and carry it out, so that you can't get anything for it. There are quite a few practical difficulties.

A lot of you have said that raising orchards would not pay because your fruit would be stolen. I do not think there is anything to that at all, because there are commercial orchards all over the country that have very little trouble. If you have trees enough in one locality — and you must have, to make it worth while— you can protect them without any trouble. In fact, you have to have a man on duty there while the apples are ripening, and perhaps have a couple of dogs there, or something like that.

There is a man here named Jackson who has made a very great success of his orchards. Last year he sold a thousand barrels of the Mackintosh apple, worth $10 000, off land that he planted a few years ago, which only cost him $10 or $15 an acre — cut over land. I do not see why, if he can do that, we cannot do it. And we are trying it on a comparatively small scale.

What I wanted to bring out to-day is, what are you gentlemen doing? not what is your theory about it, so much as what are you doing now? It is a condition, not a theory. I am telling you what we do, and I would like to know what some of you are doing to-day. It is a big problem.

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*Superintendent Water Works, Greenwich, Conn.

You have thousands of acres of land, good, fertile land — and what are you doing with it? Are you allowing it to grow up to briers and go back to cheap land, or are you planting it, or what are you doing with it? That is what I want to know.

MR. GARRATT. In Hartford most of our land is rough land. The amount of fertile land, meadow land, was relatively small and was near the reservoirs. On rough land we have a definite forestation plan, whereby each season we plant about 30 000 pines, red, Scotch and white. The brush on those plantations is kept cut for the first few years. It is an expensive proposition to grow them now, but what they will return in the future we are not in a position to say.

The open land, the good land near the reservoirs, we are planting to grass. It is plowed and fertilized with commercial fertilizer, treated with lime and sowed down.

The land that is already forested is trimmed out as our force allows and made into lumber, cord wood, ties and telegraph poles.

MR. MCLEAN. I think it has been established that it is possible to take care of the land if it is nothing but a forest. We have men who haven't much to do in the winter time, and instead of letting them be idle it is best to send them into the woods to chop down the wood and sell it; otherwise I think we will be compelled to give up the land to the people who own it and who do something with the soil, and filter our water. If the boys steal the fruit off the trees, that can be easily stopped.

MR. BAKER. I hope the idea won't get abroad that everywhere there is such a serious struggle between the forest weeds, as they are called, and the pine that are planted, as seems to be the experience in some places. I do not question that it may be true here in Bridgeport, but probably several if not many of those present know of good pine plantations in this country and elsewhere where there has been absolutely no trouble, or only very insignificant troubles with other growth. If the trees are properly spaced, in a very few years pine will completely cover the ground. One area in particular which I planted about ten years ago has grown up so that it is next to impossible for anyone to walk through it, the ground is so completely covered, the branches from one row of trees interlocking already with the branches from another. And that is my general observation wherever I have seen forestry work being carried on. There may be places, of course, where some of the softer woods do get in and grow so rapidly that they choke out the pines, but I think experience will show that after fifteen or twenty years the pine will be in the ascendency. The pine is a rapid grower and I think will destroy everything else.

MR. SENIOR. The difficulty we have is in cut-over land. You would not experience that on pasture land.

MR. DIVEN. I think in the long end of the struggle you will find that the pine will win.

THE DESIGN AND CONSTRUCTION OF THE GLOVERSVILLE STANDPIPE.

BY FRANK A. MARSTON.*

[*January 12, 1922.*]

The City of Gloversville, well known because of its extensive leather and glove industries, is located in the easterly portion of New York State about forty miles northwest of Albany. Its population in 1920 was 22 026.

The main water supply is derived from a number of creeks located at a distance of from three to ten miles from the city and at sufficient elevation above it to enable the supply to be distributed by gravity.

The water consumption of Gloversville varies widely, depending upon the activity of the tanning industry. In the period from November, 1919, to March, 1920, within which the tanneries were very active, the average water consumption was 2.8 million gallons per day, with a maximum rate of from 4.5 to 5 million gal. per day, and the average per capita consumption amounted to 127 gal. per day. By contrast, during July, 1920, when the tanneries were shut down, the average water consumption was 1.75 million gal. per day, with a maximum rate of from 3.0 to 3.5 million gal. per day, and the average per capita consumption amounted to but 80 gal. per day. The services are nearly all (99.2%) metered.

With the tanneries in full operation the maximum demand for water, from these industries, during the daytime, has been sufficient in the past to reduce the normal water pressure in the center of the city, from about 90 to about 65 lbs. per square inch.

According to the standard regulations adopted in 1916 by the National Board of Fire Underwriters, the maximum rate of demand for water at fires is approximately 4 760 gal. per minute, or a rate of 6.85 million gal. per day, computed by the formula, —

$$\text{Gallons per minute} = 1020\sqrt{P}\,(1-.01\sqrt{P})$$

Where P = population in thousands = 24 (estimated) 1935 population.

This maximum rate is to be taken in addition to the ordinary maximum water consumption demand based upon: "The maximum consumption for 24 hours in the past three years . . . unless conditions have so changed that this maximum will not occur again."

It is further required that for cities of 2 500 population or over, "ten hours' fire flow could be obtained."

The fire demand rate of 6.85 million gal. per day for a period of ten hours requires a total amount of 2.86 million gal. To provide water storage to meet these conditions would require the construction of a reservoir,

* Of Metcalf and Eddy, Consulting Engineers, Boston, Mass.

preferably of at least 5 million gal. capacity. Such a reservoir has been proposed as a part of the future construction program of the Water Works Department; but in view of the financial situation of the Department and the need of reinforcing the distribution pipe system, the local authorities felt that the cost involved by the construction of a reservoir of 5 million gal. at the present time was not warranted and that the expedient of building a standpipe with a capacity of about one million gallons would tide over the situation until some future time when a larger appropriation could be made.

From the point of view of fire protection the standpipe, by reason of its small capacity, would have but little effect. During the first hour or two of the fire, to be sure, unless the number of fire streams used was large, the pressure would be somewhat increased by the standpipe storage; but in a prolonged fire requiring upwards of a million gallons of water, the influence of the standpipe would be nearly negligible.

The standpipe will, however, have the effect of maintaining higher water pressure in the center of the city during the hours of the day when the demand from the tanneries is such as to reduce the available pressure to below desirable limits. In designing the standpipe it was assumed that its effect would be to limit the minimum pressure to 72 lb., more or less, (with the tanneries active) whereas in the past during the daylight hours (from 8 A.M. to 3 or 4 P.M.) the pressure has sometimes fallen to nine pounds, more or less, below this limit, as actually recorded by the gage in the Water Department's office.

During periods of depression in the tanning industry the maximum demand for water will be less and it is expected that the pressure will be maintained at somewhat higher figures.

Design of Standpipe.

After studying several methods of improving the pressure in the distribution system, and taking into account the various conditions involved it was decided to construct a steel standpipe, 60 ft. in diameter and 55 ft. in height, on high land near South Eagle Street in the southern part of the city. Drawings and specifications were prepared by Metcalf & Eddy, Consulting Engineers, Boston, Mass.

The standpipe rests upon a reinforced concrete foundation, and has been so located that the top of the tank is 5 ft. below the overflow level of the spillway of Rice Creek inlet, — the nearest of the several reservoirs supplying the city. Near the base of the standpipe, a 12-in. Ross pressure regulating valve has been installed, to prevent water from overflowing the top of the standpipe at times of unusually low consumption. Under the usual operating conditions, even with the minimum weekday demand, overflow is not expected to occur, due to the friction loss in the distribution system. As a protection in the event of accidental overflow, however, provision against serious damage has been made in the grading of the stand-

pipe lot and by the construction of a concrete walk around the structure at its base.

By thus locating the standpipe and providing against overflow a saving of 5 ft. in the height of the structure was realized, and its capacity made more available than would have been the case with a standpipe of equal capacity but with the top carried to the same elevation as the spillway of the reservoir.

As the cost of housing a standpipe is substantially equal to that of the standpipe itself, one of the first questions to be decided was whether or not it would be necessary to roof, or to completely house, a standpipe such as this in an exposed location.

The temperature of the water in Gloversville, during the winter, is but slightly above the freezing point. Observations made by Mr. Alexander Orr, Superintendent of the Water Department, indicated temperatures of from 36 to 38 degrees Fahrenheit between February 10 and February 14, 1920. It is to be expected that a temperature of the air of from 10 to 20 degrees below zero will be reached on several successive days, with the maximum temperature at such times but little if any above the freezing point. In order to be thoroughly informed as to what experience has shown regarding standpipes of different kinds and dimensions, a questionnaire was prepared and sent to about 300 water works located in the northern part of the United States and in Canada. The results of this inquiry were reported in a paper entitled " Experiences with Ice in Standpipes ", presented by Mr. Leonard Metcalf and published in the JOURNAL OF THE AMERICAN WATER WORKS ASSOCIATION, Volume VII, No. 4, July, 1920, pages 578 to 588.

The records fully established the fact that an open standpipe could be used safely in Gloversville, despite the cold winter climate. Furthermore, the comparatively large diameter of the standpipe (60 ft.) decreased the likelihood of trouble from floating ice or from ice forming against the cylindrical sides to an objectionable thickness.

No overflow pipe was provided, since it was believed that if constructed on the inside of the standpipe it might be torn out by ice action, and if on the outside it would soon become frozen, in case of overflow, and thus rendered useless.

SPECIFICATIONS.

In writing the specifications it was the intention to state the requirements in such a way that the bidders might be able to make use, as far as possible, of their own standard forms of joint, methods of construction, economical width of plate, and certain other features which would not affect the strength or durability of the standpipe, but would result in a material saving in cost.

Only certain portions of the specifications, of especial interest, will be mentioned.

Stresses.

The specifications required that all parts of the structure should be proportioned so that the sum of the dead and live loads would not cause the stresses to exceed those given in the following table:

Tension in plates forming sides or bottom of standpipe	12 000 lb. per sq. in. of net area
Shear on rivets	9 000 lb. per sq. in.
Shear in plates	10 000 lb. per sq. in.
Bearing pressure on rivets	18 000 lb. per sq. in.

The above allowable stresses are somewhat lower than those frequently employed for standpipes and other steel structures. The additional cost involved by the thicker plates required, appeared to be justified in view of the conditions of extreme cold and exposed location, to which the standpipe is subjected.

Plates and Structural Shapes.

"The bottom of the standpipe shall be made of steel plates $\frac{3}{8}$ in. in thickness, with single riveted lap joints."

"The sides of the standpipe shall be made with courses of steel plates varying in thickness from $\frac{5}{16}$ in. to 1 in. The stresses determining the thickness of any circumferential course of plates and the design of the vertical joints shall be the stresses computed at the line midway between the double row of circumferential riveting at the bottom of the course."

While it would have been possible with high efficiency joints to use a somewhat thinner plate for the lowest course of side plates than that specified (1 in.), it was deemed prudent, in view of all the conditions, to provide the thicker plate. One consideration which led to the adoption of this thicker plate was the fact that the results of examinations of old standpipes indicated far more serious pitting of the plates in the lowest course than in any of the other courses.

It will be noted from the above that no limitations were placed on the width of plates to be used, making it possible for the manufacturer to adopt such widths as might prove most advantageous from his point of view.

"The plates forming the sides of the standpipe shall be of such diameters that the courses shall be cylindrical and shall overlap each other inside and outside alternately.

"The circumferential joints shall be *double-riveted lap* joints. The vertical joints shall be *butt* joints with *inside* and *outside* straps."

"Rivets shall be spaced so as to make the most economical and watertight seam. The butt joints shall be so designed as to develop an efficiency of at least 70 per cent.

"The lowest course of the side plates shall be connected to the bottom plates by means of a 6-in. by 4-in. by $\frac{1}{2}$-in. steel angle placed on the inside, with the 6-in. leg double-riveted to the side plates.

"The top of the tank shall be stiffened with a 3-in. by $2\frac{11}{16}$-in. by $\frac{3}{8}$-in. Z bar placed on the outside."

Quality of Steel.

It was required that all of the steel should be made by the open hearth process conforming to the requirements of the standard specifications of the American Society for Testing Materials.

For the plates "flange steel" was specified, having a tensile strength of 55 000 to 65 000 lb. per sq. in.

Planing and Drilling Plates.

"All caulking edges of plates and of the butt straps shall be bevelled slightly by planing.

"In plates $\frac{3}{8}$ of an inch or less in thickness the rivet holes except for butt joints may be punched full size from the faying surface of the plate.

"In plates more than $\frac{3}{8}$ inch and less than $\frac{7}{8}$ inch in thickness and for butt joints in thinner plates, the rivet holes may be either drilled full size, or punched at least $\frac{3}{16}$ inch less in diameter than the finished diameter, and drilled or reamed to the finished diameter.

"Rivet holes in plates $\frac{7}{8}$ inch in thickness or greater shall be drilled.

"The finished diameter of all rivet holes shall not exceed the diameter of the rivet to be used by more than $\frac{1}{16}$ inch."

Proposals for Construction.

Bids for the construction of the standpipe were opened April 5, 1921. Seven bids were received, as shown in Table 1, the lowest being that of the Pittsburgh-Des Moines Steel Company. The estimated weights shown were computed by Metcalf & Eddy. It will be noted that the estimated price per pound varies from 7.5 cents to 11.4 cents per lb. for the steel standpipe erected, including sand blasting and painting, but exclusive of the reinforced concrete foundation, which was constructed under another contract.

It is of special interest to compare the proposed thicknesses of plates and widths of plates as submitted by the several bidders, inasmuch as the bidders were only limited in regard to the minimum and maximum thickness of plates. The accompanying diagram, Fig. 1, shows the thickness of plates on an enlarged scale and the depth below the top of the standpipe (equivalent to the depth of water) on a reduced scale. The series of stepped lines indicates the thickness and weight of plates proposed by the several bidders. The full line shows the design proposed by the Pittsburgh-Des Moines Steel Company, the low bidder to whom the contract was awarded.

The diagonal lines indicate the theoretical required thickness for an allowable tensile stress of 12 000 lb. per sq. in., and joint efficiencies of 100, 90, 80 and 70 per cent., respectively. While such a diagram cannot be relied upon solely in a study of the strength of the joints, it is of aid in indicating the location of the critical joints and in forming judgment as to the comparative value of the several bids.

TABLE 1.

GLOVERSVILLE, N. Y. WATER WORKS.

Comparison of Bids Received April 5, 1921 for Steel Standpipe (60 ft. diameter by 55 ft. high) and for Standpipe Foundation.

Name.	Address.	Days to Complete after Contract.	Price.	Estimated Weight, Lb.	Price per Lb. based on M & E estim'd Weights.
1. Pittsburgh-Des Moines Steel Co.	50 Church St., New York City	150	$24 940	331 000	7.5c
2. Tippett and Wood,	162 Howard St., Phillipsburg, N. J.	130*	25 990	300 000	8.7
3. Chicago Bridge and Iron Works,	30 Church Street, New York City	150†	26 700	325 000	8.2
4. Riter-Conley Co.	Pittsburgh, Pa.	150	29 170	300 000	9.7
5. Walch's Holyoke Steam Boiler Works	110 Appleton St., Holyoke, Mass.	150*	34 357	362 000	9.5
6. Dover Boiler Works,	50 Church St., New York City	150	36 220		
7. The Petroleum Iron Works Co., Inc.,	25 West 43rd St., New York City	200	39 825	348 000	11.4
Foundation (concrete) including substructure of valve chamber.					
Morrell Vrooman, Inc.‡	Gloversville, N. Y.	60	$5 662.12	Item 1	
			947.08	Item 2	
			$6 609.20	Total	
Walter Kidde & Co., Inc.,	140 Cedar St., New York City	45	$8 200.00	Item 1 — 45	
		15	1 100.00	Item 2 — 15	
			$9 300.00	Total	
A. E. Brace Construction Co.,	39 Hamilton St., Gloversville, N. Y.	90	$9 055.86	Item 1	
			696.00	Item 2	
			$9 751.86	Total	

Total for standpipe, excluding engineering:

Steelwork	$24 940	Contract price.
Foundation	6 609	Contract price = 26.5% of steelwork.
Total	$31 549	

* Working days. † Verbal. ‡ Awarded contract.

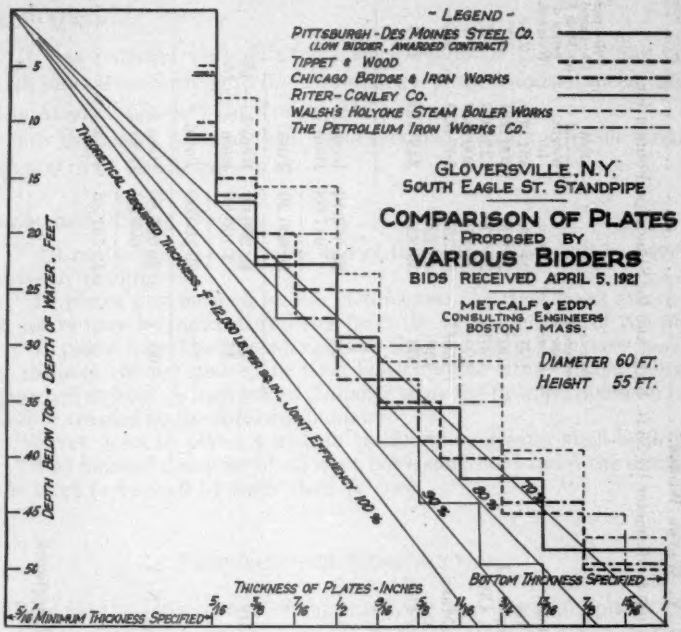

- LEGEND -
PITTSBURGH - DES MOINES STEEL CO.
(LOW BIDDER, AWARDED CONTRACT)
TIPPET & WOOD
CHICAGO BRIDGE & IRON WORKS
RITER - CONLEY CO.
WALSH'S HOLYOKE STEAM BOILER WORKS
THE PETROLEUM IRON WORKS CO.
GLOVERSVILLE, N.Y.
SOUTH EAGLE ST. STANDPIPE
COMPARISON OF PLATES
PROPOSED BY
VARIOUS BIDDERS
BIDS RECEIVED APRIL 5, 1921
METCALF & EDDY
CONSULTING ENGINEERS
BOSTON - MASS.
DIAMETER 60 FT.
HEIGHT 55 FT.
THEORETICAL REQUIRED THICKNESS, f = 12,000 LB. PER SQ. IN., JOINT EFFICIENCY 100 %
DEPTH BELOW TOP - DEPTH OF WATER, FEET
THICKNESS OF PLATES - INCHES
BOTTOM THICKNESS SPECIFIED
5/16 MINIMUM THICKNESS SPECIFIED

FIG. I.

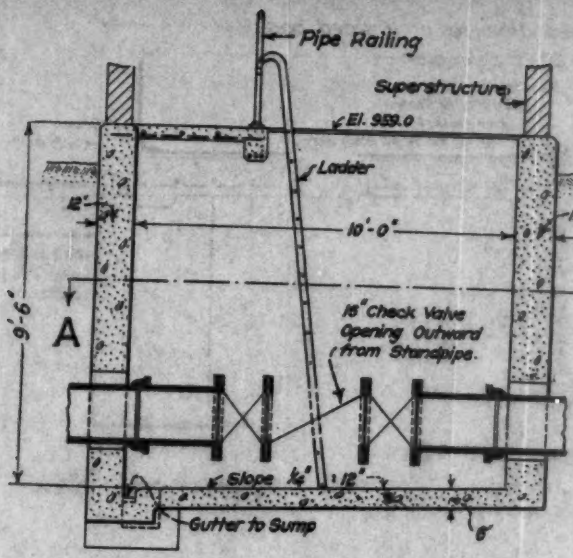
STANDPIPE FOUNDATION.

The drawings and specifications for the reinforced concrete standpipe foundation and the valve chamber substructure were also prepared by Metcalf & Eddy, and contract for the construction was awarded to Morrell Vrooman, Inc., of Gloversville, the lowest bidder. The principal details are shown in Fig. 2.

The foundation consists essentially of a circumferential wall of concrete, 3 ft. wide and about 7 ft. high, and is entirely in excavation, the only fill required being adjacent to the wall at the top, and very small in amount. The material excavated was such that no sheeting was required in excavating the trench for the foundation wall. No forms were used for the wall except the upper part on the exterior where they were necessary in order to obtain the desired finish.

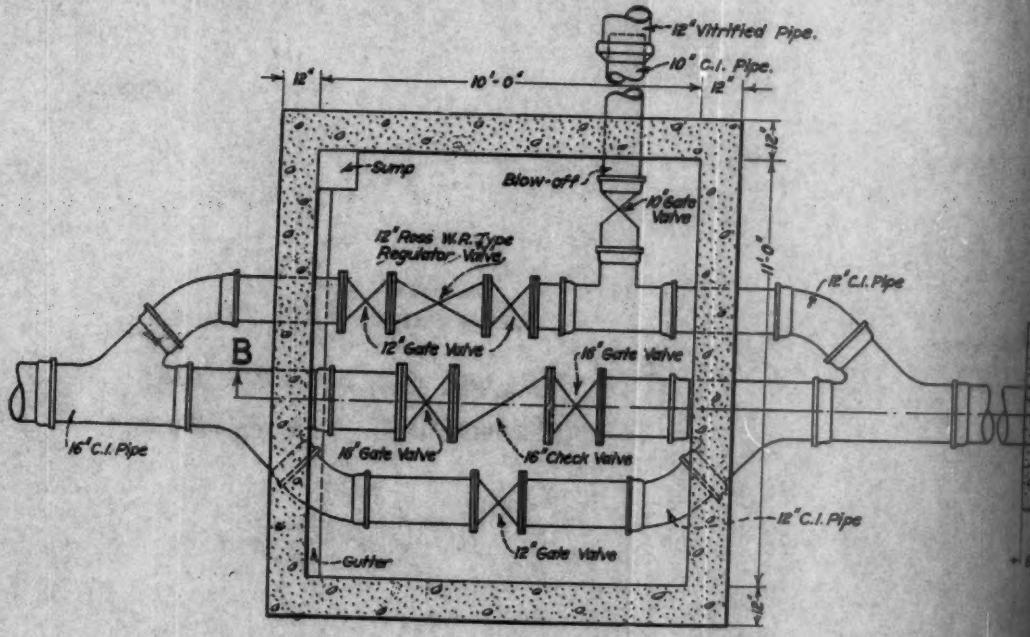
The foundation slab, 12 in. in thickness, is reinforced with ½-in. round deformed steel bars 12 in. on centers in two directions at right angles to each other.

Over the inlet pipe a small manhole is provided, affording access to the joint between the inlet pipe and the bottom plate of the standpipe.



VALVE CHAMBER

SECTIO



SECTIONAL PLAN

Fig. 2.
N. E. W. W. ASSOCIATION.
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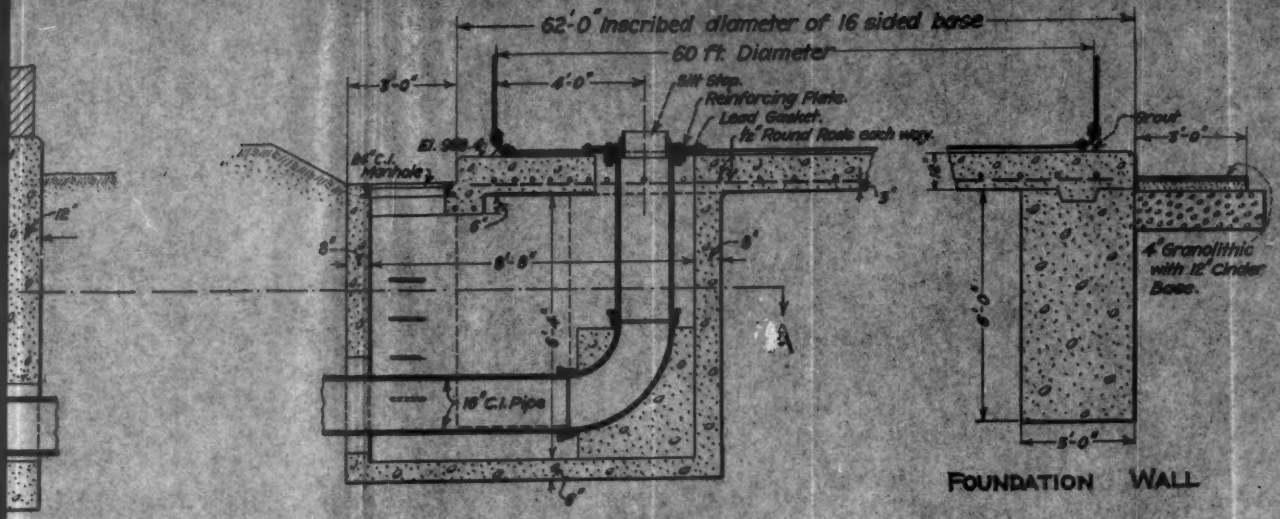
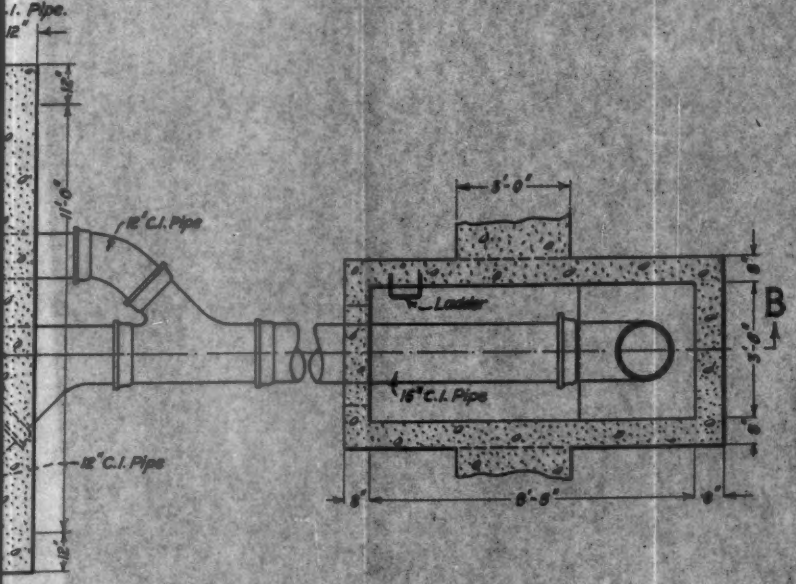
MARSTON ON
GLOVERSVILLE STANDPIPE.



PIPE MANHOLE

FOUNDATION WALL

SECTIONAL ELEVATION B-B



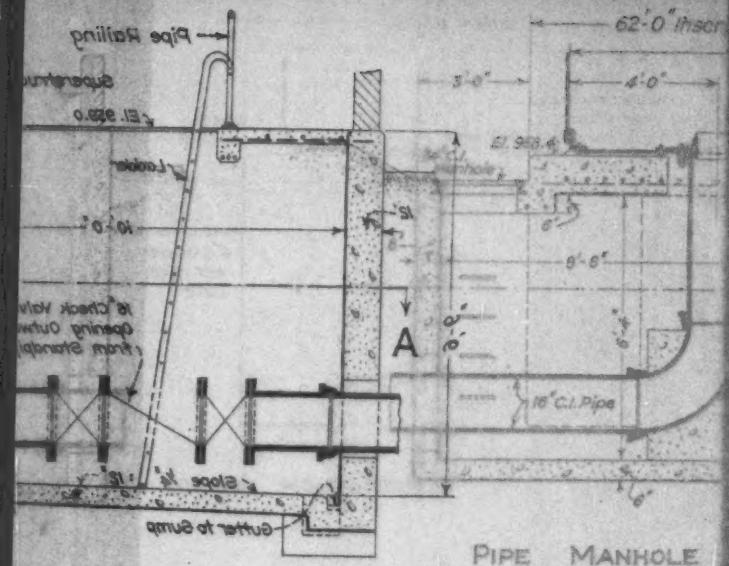
ECTIONAL PLAN A-A

GLOVERSVILLE, N.Y.
SOUTH EAGLE ST. STANDPIPE

VALVE CHAMBER AND STANDPIPE FOUNDATION

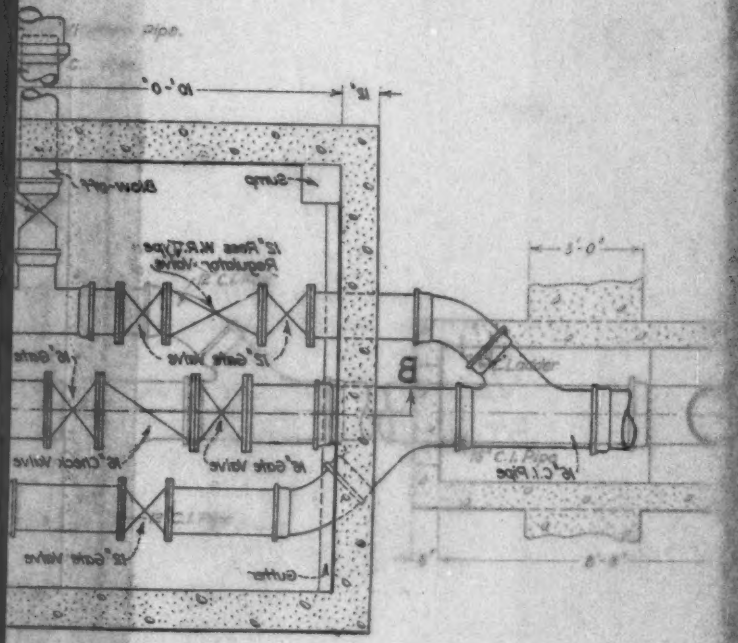
1921

METCALF & EDDY
CONSULTING ENGINEERS
BOSTON - MASS.



PIPE MANHOLE

SECTIONAL ELEVATION



SECTIONAL PLAN A-A

Valve Chamber.

The valve chamber, a plan of which is shown in Fig. 2, houses the valves controlling the operation of the standpipe.

The inlet pipe is divided into three lines where it passes through the valve chamber. The first line contains a 12-in. Ross W-R type regulator valve, by means of which water is allowed to enter the standpipe up to a point a few feet below the top. When it attains this height the regulator valve will close, stopping the entrance of water and preventing overflow of the standpipe. A gate valve is provided on either side of the regulator valve, so that the latter can be removed without throwing the standpipe out of service. This line also contains a branch with a gate valve, to serve as a drain for emptying the standpipe.

The second line contains a 16-in. check valve arranged to open outward, allowing water to leave the standpipe, but preventing the entrance of water through this connection. A gate valve is provided on either side of the check valve to permit its being removed while the standpipe is in service.

The third line is a by-pass and contains a gate valve. In case of damage or interruption of service in either one of the other two lines the by-pass can be opened and the standpipe kept in service.

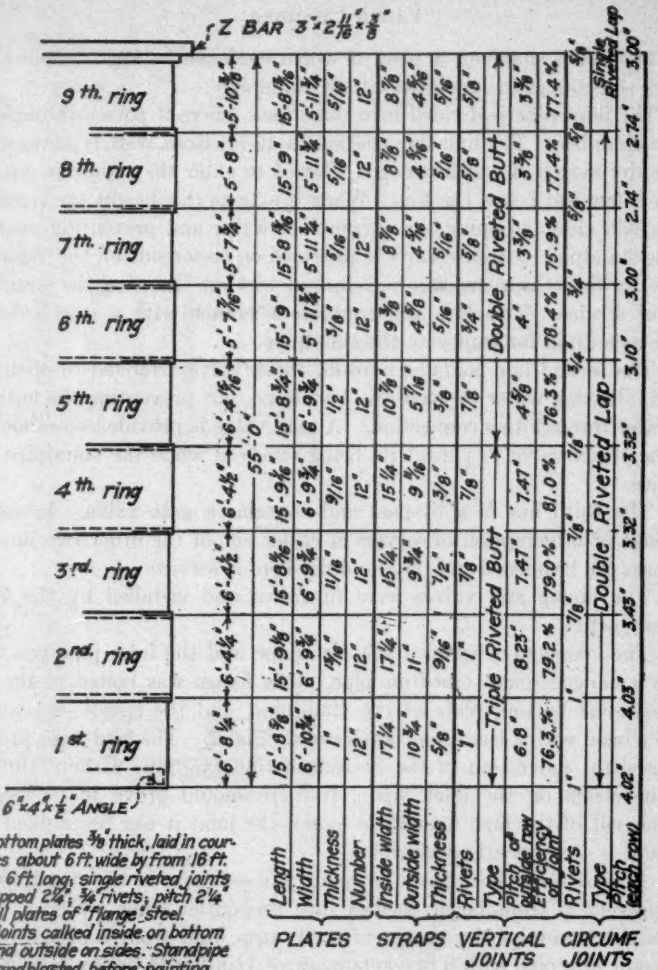
The piping and valves were furnished and installed by the Water Department.

The connection between the standpipe and the inlet pipe was made with a flanged-spigot cast-iron pipe. The flange was bolted to the reinforced steel bottom plate of the standpipe, and the spigot end was set into a bend with a lead joint, as shown on Fig. 2. The lead joint provides for a slight movement of the bottom of the standpipe without throwing undue strain on the inlet pipe. If there should prove to be frequent movement of the pipe tending to loosen the joint it can be caulked tight since it is conveniently accessible.

Provision has been made to retain the sediment in the standpipe and to prevent it from being washed into the outlet when water is drawn from the standpipe, by means of a silt stop built from a piece of 16-in. wrought iron pipe with 6 brackets made of 1½in. by 1½ in. by ½ in. angles, each four inches long, riveted to the sides of the wrought iron pipe, and so located that the pipe will extend four inches above the floor of the standpipe. This is not fastened in place, but is sufficiently heavy to retain its position without being dislocated by the current of water.

Construction of Standpipe.

Bids for the construction of the steel standpipe were opened on April 5 and the contract with the Pittsburgh-Des Moines Steel Company was signed on April 8, 1921. It will be seen from Fig. 3, whereon the principal design details are given, that the tank is 55 ft. high and has nine courses



Bottom plates 3/8" thick, laid in courses about 6 ft. wide by from 16 ft. to 6 ft. long; single riveted joints lapped 2½"; ¾" rivets; pitch 2¼"
All plates of "Flange" steel.
Joints calked inside on bottom and outside on sides. Standpipe sandblasted before painting.
Manhole 18"×22" in bottom course.
Outside ladder of ¾" round rungs and 3"×⅜" side bars.
Estimated total weight = 331,000 lbs.
Laps, straps, angles, Z bars, ladder and rivet heads est. 16% of total.
Capacity 1,163,000 gallons.
Cost of Standpipe, $24,940.6 (7.5¢ per lb.)
Cost of foundation $6,609.20
Total = $31,549.20 = $27,150 ± per million gallons.

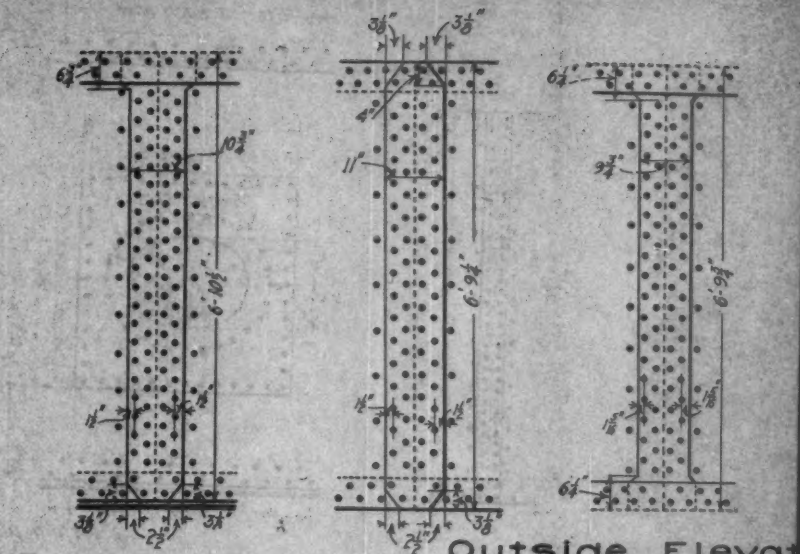
GLOVERSVILLE, N.Y.

SOUTH EAGLE ST. STANDPIPE
55 FT. HIGH × 60 FT. DIAMETER

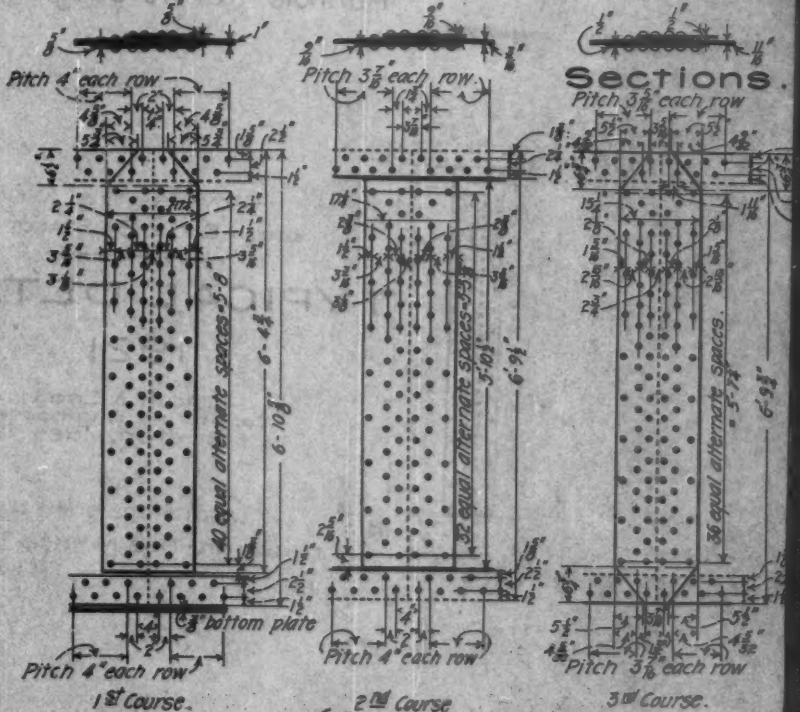
DETAILED AND ERECTED BY
PITTSBURGH-DES MOINES STEEL CO.

METCALF & EDDY
CONSULTING ENGINEERS
BOSTON - MASS.

FIG. III.



Outside Elevat



Triple Riveted Butt Joints

Inside Elevat

FIG. 4.
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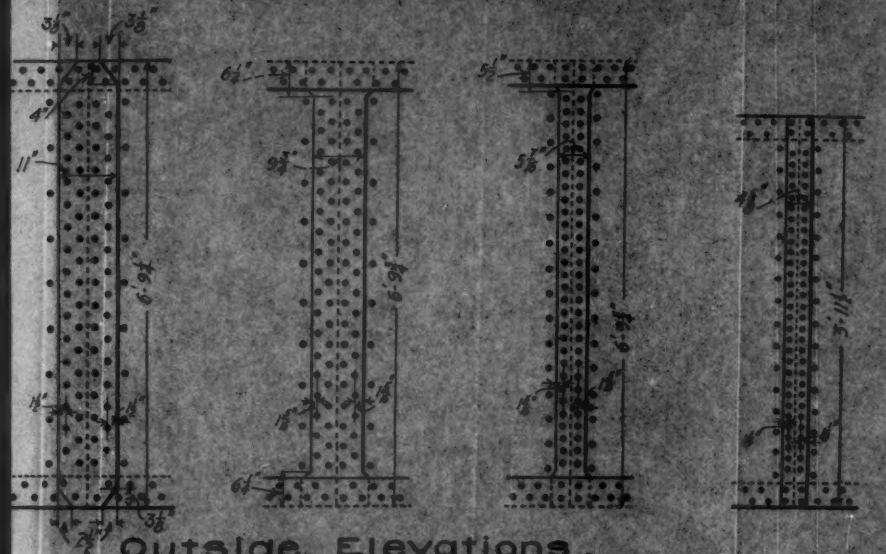

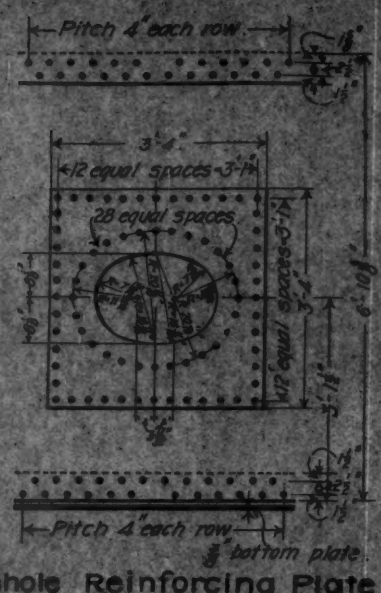

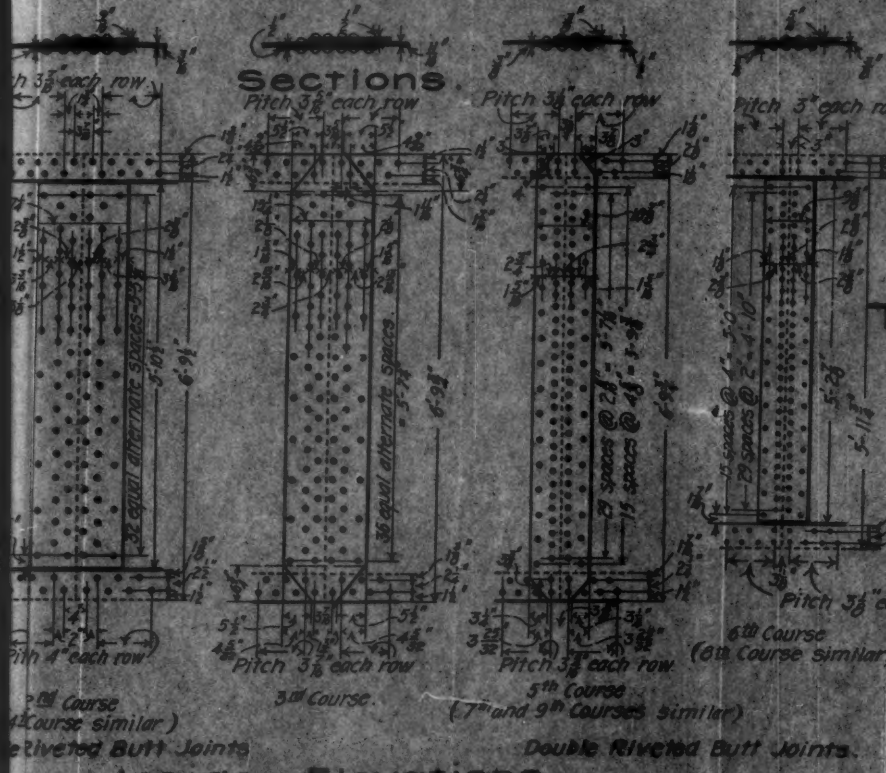

GLOVERSVILLE, N.Y.
SOUTH EAGLE ST. STANDPIPE

TYPICAL DETAILS

1921

Metcalf & Eddy
Consulting Engineers
Boston, Mass.

Details designed by
Pittsburgh-Des Moines Steel Co.

of 12 plates each, the plates varying in width from 6 ft. $10\frac{3}{4}$ in. to 5 ft. $11\frac{3}{4}$ in. and in thickness from 1 in. at the bottom to $\frac{5}{16}$ in. at the top. The rivets vary in diameter from 1 in. to $\frac{5}{8}$ in. Typical details are shown on Fig. 4.

After the reinforced concrete foundation had been completed the first shipment of steel plates was delivered (on June 21) and on July 2 the erection of the bottom plates began. They were assembled, riveted together, the angles attached to the circumference, and all joints caulked, with the bottom supported on wooden horses three feet above the concrete foundation. Four jack screws were then inserted to support the interior plates, and the wooden horses removed. The exterior or periphery

PLATE I.

of the bottom was supported on blocking in such a way that it could easily be lowered by removing one block at a time. This use of blocking, instead of jackscrews, around the edge, may at first thought seem objectionable, as it permitted the plates to sag as much as 4 in. between the blocks, as one after another of the blocks was removed. But as far as could be determined no damage to either plates or joints resulted.

The photograph (Plate I) indicates the general manner of lowering the blocking, one man operating each of the four jack screws and other men being located around the periphery of the bottom to remove the blocks. In this way the bottom was lowered on to the foundation within a period of about two hours, in a successful manner and without undue strain on any of the plates, the gang required consisting of one foreman, seven iron workers and three laborers.

The jack screws above referred to, passed through threaded flanges or nuts, riveted to the upper side of the bottom plates (see Plate II). These flanges were left in place and the threaded hole closed, upon removal of the jack screws, by means of a special screw plug. The lower ends of these jack screws were hemispherical in shape and rested on small steel pads

set on top of the concrete foundation. These pads, when the tank bottom had been lowered to within 18 in. of the foundation, were removed from under the jackscrews so that the latter rested directly upon the concrete. This resulted in some movement of the jack screws as the bottom was lowered further, and damaged the threads of the screws, but so far as could be determined resulted in no damage to the plates.

PLATE II.

With the exception of the bottom rivets, all of which were driven by pneumatic hammers, the riveting up to the sixth course was done by a compression riveter, or "gap riveter" as it is sometimes called. This equipment is shown in Plate III. The caulking was done with pneumatic caulking tools, using a round nosed chisel. Above the sixth course, pneumatic hammers were used as the plates were thinner and better progress could be made in that manner.

Stagings used during the riveting and caulking processes were supported by brackets bolted to the sides of the standpipe, for which provision had been made in the fabrication of the plates. The holes for the bracket supports were closed later by rivets. The type of staging used is illustrated in Fig. 6. The "dolly bars" use in bucking-up against the rivet head were swung from a rope or chain supported by the upper edge of the side plates. They weighed about 100 lb. each. For the riveting of the bottom

plates the dolly bars were supported by a so-called "bucking-up stool." This consisted of a plank, one end of which was inserted under the lower end of the vertical dolly bar, with a block on the under side of the plank to act as a fulcrum, and with the operator sitting on the other end of the plank, using it as a lever to force the dolly bar up against the rivet head.

PLATE III.

For the erection of the side plates a structural steel, guyed derrick was used, the mast being about 90 ft. in length and the boom about 80 ft. This derrick was erected after the tank bottom had been lowered on to the concrete foundation. Its foot was supported on wooden blocking resting directly on the tank plates which in turn rested on the concrete underneath. The erection of the derrick was accomplished by the use of a 60-ft. gin pole made up of two 30 ft. 8 in. x 8 in. timbers spliced with 2-in. planks. After the erection of the standpipe and before sand blasting and painting were begun, the derrick and boom were dismantled and hoisted out piece by piece by means of the gin pole.

After the erection of the sixth course of side plates, but previous to the removal of the derrick, grouting operations were commenced, to fill the space between the tank bottom and the concrete foundation. The

grout was composed of a mixture of cement, sand, and water in the proportions of one part by volume of Portland cement to one part of fine sand, with only sufficient water to make the mixture flow freely.

Threaded flanges were provided in each of the plates forming the bottom of the standpipe, into which were inserted 2-in. wrought iron grouting pipes limited in length to 24 in., in order to avoid undue upward pressure upon the bottom plates. Through these grout was poured until the space between the bottom of the tank and the concrete foundation was filled as completely as possible. Some difficulty was experienced in filling

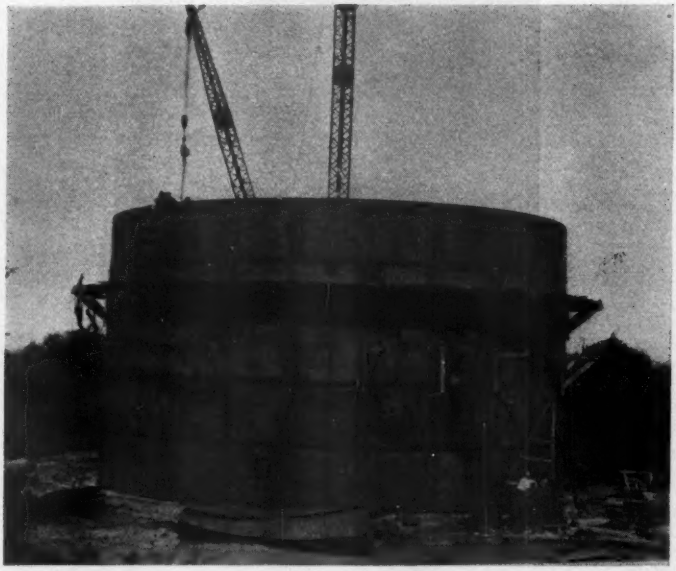

PLATE IV.

this space, because of buckling of the plates due in part to the grout pressure and partly to expansion from the heat of the sun. Some upward movement of the center plates may have occurred when the derrick was removed, so that it cannot be said that the grouting operation was entirely satisfactory. It is believed to be somewhat more satisfactory than the sand-cement cushion method of bedding the bottom plates. Neither method seems to give ideal results, although both methods have been used successfully. It is anticipated, however, that with water in the tank a fairly uniform pressure of the structure on the grouted foundation will be obtained. Upon completion of the grouting the grout pipes were removed and the threaded flange holes closed with screw plugs.

In the erection of the plates very little work was required to fair the holes, — that is, to make the holes match. While drift pins were used to

a slight extent and in an unobjectionable manner, it may be said, in fairness to the contractor, that the layout of the plates was unusually good. Practically all of the holes were reamed after the plates were set in place, to ensure a good surface for bearing against the rivets.

The small openings left in the top and bottom of each vertical butt joint were closed by driving in steel wedges or "dutchmen" and by caulking over the top of the wedge.

The specifications required that the plates should be given one coat of boiled linseed oil, before leaving the shop. The contractor, however, was allowed to omit the oiling of the plates except on the laps, since it was believed that the slight rusting which would occur in the body of the plate would aid in softening the mill scale and facilitate the sand blasting. Very little rust formed on the plates before they were painted, so it was difficult to determine whether the omission of the oiling aided the sand blasting or not.

Sand Blasting.

Before the first coat of paint was applied the surface of each plate was thoroughly cleaned with the sand blast, using a local sand which was discharged through a nozzle with air pressure from a sand atomizer. By this means all loose scale and rust were removed. The first coat of paint was applied immediately after the sand blasting had been completed and before the cleaned surface had an opportunity to rust. Both sand blasting and painting were done from a staging suspended from trolleys supported by the Z-bar attached to the top of the tank.

Painting.

The inside and outside of the standpipe were given three coats of paint mixed according to the following formulæ:

For interior of standpipe:

First coat — 100 pounds paste red lead, 2 gallons pure boiled linseed oil, 8 pounds fine litharge mixed in 1 pint raw linseed oil and 1 quart turpentine.

Second coat — Same as above, with the addition of ¾ pound of paste lamp black.

Third coat — 100 pounds paste red lead, 4 pounds paste lamp black, 2.25 gallons boiled linseed oil, 8 pounds fine litharge mixed in 1 pint raw linseed oil and 1 quart turpentine.

For exterior of standpipe:

First coat — 100 pounds paste red lead, 2.5 gallons raw linseed oil, 1.5 pints turpentine, 1.5 pints drier.

Second coat — Same as above with the addition of ¾ pounds of paste lamp black.

Third coat — (Dark green) 100 pounds paste red lead, 12½ pounds paste chrome yellow, medium, 7½ pounds paste Prussian blue, 4.54 gallons of raw linseed oil, 1 pint turpentine, 1 pint drier.

Paint materials were received on the work in the original packages and mixed at the site of the work. During the painting operations one man was continuously employed in keeping the paint in the stock barrel thoroughly mixed.

Both sand blasting and painting were done by the iron workers who erected the tank.

TABLE 2.

PROGRESS DATA.

	Date 1921.	Elapsed Time.
STANDPIPE:		
Asked for bids	March 1	
		35 days
Opened bids	April 5	
		3 days
Contract signed†	April 8	
		29 days
Shop drawings received	May 7	
		7 days
(Steel received at shop about	May 12)	
Shop drawings approved*	May 14	
		38 days
First steel shipment arrived	June 21	
		11 days
Erection started	July 2	
		19 days
Bottom lowered	July 21	
		34 days
Erection completed	Aug. 24	
		23 days
Sand blasting and painting completed	Sept. 16	
Total time from signing of contract		161 days
(Contract agreement		150 days)
FOUNDATION:		
Asked for bids	March 1	
		35 days
Opened bids	April 5	
		3 days
Contract signed	April 8	
		25 days
Ground broken	May 3	
		3 days
Concreting started	May 6	
		14 days
Foundation completed**	May 20	
Total time from signing of contract		42 days
(Contract required completion of this part of the work on or before June 1, 1921.)		

† Steel ordered soon after.

* Fabrication started soon after this.

** Except for grading and granolithic walk, which were completed after standpipe was erected.

Testing.

After the erection had been completed the tank was filled with water, for testing. The amount of leakage was found to be very slight, which fact reflects much credit upon the thorough manner in which the erection work was performed. A few seams required a little caulking and a few rivets which showed small leaks were touched up with the caulking tool. One rivet which was broken was cut out and replaced.

The time required for the various parts of the work are indicated in the progress table (Table 2). It will be noticed that the total time required for completing the steel standpipe contract, including sand blasting and painting, from the date on which the contract was signed, was 161 days. The time limit specified in the contract was 150 days. A delay of several days was caused by breakdown of the air compressing plant.

Cost of Standpipe.

The cost of the standpipe, classified under certain general headings, is given in Table 3. The total cost of the structure, including foundations, sand blasting and painting, valve chamber and piping, but excluding engineering, administration, cost of land and fencing, is $35 015.80, equivalent to $30 000 per million gal. of capacity. The fencing, constructed by the Cyclone Fence Company, 8 ft. in height with three strands of barbed wire on the top, cost about $1.55 per linear foot, erected. This sum includes two swinging gates. The above cost figures do not include the cost of the small trees, which were set out by the Water Department. These were obtained from the nursery maintained by the Department, which for a number of years has made a practice of systematic planting on the watersheds and other lands in its charge. In this and other ways Mr. Orr has shown wise management in the handling of many perplexing problems in connection with the operation of the water works.

It is a pleasure to commend the conscientious manner in which the construction of this structure was supervised by the resident engineer, Mr. Fred W. Carlson, to whom the writer is indebted for much of the information relating to the construction work.

The work of the contractor, also, deserves commendation, as it was evident from the start that not only those in authority in the company, but also the erecting crew, intended to do first-class work in strict accordance with the specifications. The shearing of the plates, the alignment of the joints, the forming of the rivet heads, the caulking and all of the mechanical operations, were extremely well done.

TABLE 3.

GLOVERSVILLE, N. Y.

COST OF SOUTH EAGLE STREET STANDPIPE, FOUNDATION, AND CONNECTION WITH MAINS. BUILT IN THE SUMMER OF 1921.

Tot. wt. 331,000 lb.; equiv. cost per lb. 7.5c.

Standpipe contract (Pittsburgh-Des Moines Steel Co.)			$24 940.00
Foundation, gate chamber, 12″ vitrified pipe, blow-off and grading			6 609.20
Castings:			
4	16″ x 12″ Y br., 3 877 lbs. @ .08½	$329.55	
1	12″ x 10″ tee, 540 lbs.		
1	16″ 90° bend, 760 lbs.		
4	12″ 45° bend, 2416 lbs. @ .07½	181.20	
1	16″ F & S p. 4 feet, 4 inches, 815 lbs., @ .09¼	75.39	
2	16″ F & S p. 24 inches, 651 lbs., @ .10¼	66.73	775.48
2	12″ F & S p. 3 feet, 540 lbs. @ .10¼	55.35	
1	12″ F & S p. 2 feet, 7 inches, 262 lbs. @ .10¼	26.86	
1	12″ F & S p. 12 inches, 121 lbs. @ .10¼	12.40	
	Manhole casting and cover	16.00	
	Gate box casting	12.00	
Gate valves, etc.:			
2	16″ flg. gates @ 153.00	306.00	
3	12″ flg. gates @ 81.00	243.00	
1	10″ h & s gate	60.00	1 305.62
1	16″ ck. valve	143.10	
1	16″ hub gate	143.00	
1	12″ Ross altd valve	410.52	
Connecting gate chamber with main in street and gate chamber with standpipe			
	36′ 16″ c. i. p., 3 900 lbs. @ 64.00	$124.80	
	1 16″ sleeve, 280 lbs. @ .07½	21.00	180.40
	692 lbs. lead @ .05	34.60	
Labor account, $107.50, $144.00, $69.00			320.50
Freights			34.60
Gate House (of tapestry brick with raked joints, 11′ 4″ x 12′ 4″ plan, by about 10′ high (approx. $0.60 per c.f.)			850.00
Capacity of Standpipe 1 163 000 gal.			
Total cost per m.g. excl. eng'g., administration, land and fencing			30 000.00
Total cost			$35 015.80

DISCUSSION.

MR. A. O. DOANE.* The Metropolitan District Commission has just awarded a contract for a steel tank to be built at Arlington Heights which will be 61 ft. high and 75 ft. in diameter. We have had several stand pipes built since the work commenced, and have tried various methods of designing. In the previous ones the policy had been of designing the standpipe complete; that is, giving the size and location of the rivets and all other details.

In this particular instance we have done very much the same as Metcalf & Eddy, the difference being simply in the matter of detail rather than in the matter of principle, largely from the same considerations that Mr. Marston mentioned, of allowing a reasonable and proper latitude to

* Division Engineer Metropolitan Water Works.

the contractor in selecting his height of plates and in the general detail of carrying on the work, and at the same time making sure that the standpipe will have the desired strength.

In this case, instead of specifying a maximum allowable stress of 12 000 lbs. per sq. in. of net section in the steel plates, we have given a net formula which takes into consideration the efficiency of the joints, — the joint to be designed by the contractor with certain limitations and checked up by the engineer. In the case of any of the vertical joints the strength of the joint must be at least $4\frac{1}{2}$ times as great as the bursting pressure at the bottom of the joint. It was specified that all joints should be of the butt type, with inner and outer cover plates; but there was no limitation made as to the number of rows of rivets in the vertical joints. It was also specified that no matter how the formula worked out, no side plate should be less than $\frac{3}{8}$ in. in thickness. The bottom plates of the standpipe must be not less than $\frac{3}{8}$ in. in thickness. The general detail of the standpipe was not very much different from the one shown here, except that the circumferential seams were single instead of double riveted.

The bids that we received seemed to show that there was a pretty general agreement amongst the bidders in the matter of the thickness of plates proposed in the different bids. The efficiency of the joints proposed by the successful bidder was checked over and found to be correct.

The specifications provided that the water pressure governing the designs of any course of side plate should be taken at the bottom of the course. The depth of water assumed to be in the tank, and the pressure per foot in depth, were also given.

The principal point of difference between the specifications that Mr. Marston mentioned and the Metropolitan specifications was in following the provisions of the boiler rules rather than the structural practice of giving the allowable stresses. As no construction work has been done we cannot tell exactly how this method of specifying will work out, but from the way the bids were received and the general agreement amongst different bidders it seeme to have worked out pretty well in this particular instance; and it has the advantage that Mr. Marston mentioned of probably producing a somewhat less cost than if we tried to go into minute detail and tying the contractor up in all sorts of ways, though that is impossible to tell, especially under the present conditions of business when many contractors seem willing to sacrifice profits in order to keep their works running.

Mr. Charles W. Sherman.* What were the bids, Mr. Doane? What was the accepted bid?

Mr. Doane. There were eight bids ranging from $29 737 to $49 820; the price bid included taking down and disposing of an existing standpipe, 60 ft. high and 40 ft. in diameter.

Mr. Sherman. How does that work out on the pound basis, — do you know?

* Of Metcalf & Eddy, Boston, Mass.

MR. DOANE. It is almost exactly five cents a pound for the lowest bidder.

MR. SHERMAN. Is that standpipe to be enclosed in a tower?

MR. DOANE. Yes, the standpipe is to be enclosed in a masonry tower, so that we were not so much concerned with the effect of severe weather and severe winds, though from our experience with other tanks and from other people's experience, we feel that the tank is so constructed that it will take a violent wind to effect it. The capacity is about 2 000 000 gallons.

We also plan to have the tank in this case lowered onto a sand and cement cushion instead of using the grouting process. I have personally tried both ways and I rather lean to the sand and cement method, though each has its advantages and very decided disadvantages. I do not think there is any entirely satisfactory way of supporting the bottom plates on the foundation.

MR. G. A. SAMPSON.* What was the price on the Gloversville and East Chicago standpipes for sand blasting and painting?

MR. MARSTON. The Gloversville was 7½ cents per pound, including sand blasting and painting; the East Chicago was 6½ cents including sand blasting and painting. I think Mr. Doane said 5 cents a pound did not include sand blasting and painting.

MR. DOANE. No, that does not include sand blasting and painting, but I think the sand blasting and painting would be around a half cent or a little more.

MR. REEVES J. NEWSOM.† How long is it expected that the paint will last?

MR. DOANE. I can perhaps throw some light on that. From our experience with painting that has been thoroughly done, I should say it ought to last five or six years anyway, and does actually last that. A smaller tank that I know of, which has one layer of Gilsonite paint over the red lead, and is enclosed in a building, was painted ten years ago and it is not at all in bad shape now. Ice, of course, makes a great deal of difference, — also exposure to the weather. If you have ice going up and down it will scrape any kind of paint off.

* Of Weston & Sampson, Boston, Mass.
† Water Commissioner, Lynn, Mass.

RELATIVE TO THE REPORT OF THE AMERICAN COMMITTEE ON ELECTROLYSIS

The American Committee on Electrolysis has just issued its 1921 report, superseding its preliminary report of 1916. This report embodies such statements of facts and descriptions, and discussions of methods of electrolysis testing and electrolysis mitigation as the members of the committee have been able thus far to agree upon unanimously. In the preface, signed by Bion J. Arnold, Chairman of the Committee, the following statement is made:

"While this report supersedes the preliminary report of 1916, it should, unless the principals see fit to discontinue the work of the main committee, be considered as in the nature of a progress report and not as final, as it is impossible at the present time to answer finally many of the outstanding questions involved. Also it is to be understood that the report is confined to the technical and engineering aspects of the subject and does not attempt to deal with matters of policy or with legal questions, such as the rights and responsibilities of the several interests concerned."

The report comprises five chapters. Chapter One sets forth principles and definitions. Chapter Two is devoted to a detailed discussion of design, construction, operation, and maintenance of railways and underground structures affected by electrolysis, and to a discussion of questions involving the interconnection of affected structures and railways, ending with a summary of good practice. Chapter Three gives a discussion of the fundamentals of the whole question of electrolysis surveys, their purpose, scope, possibilities and interpretation, and also a discussion of the instruments suitable for electrolysis testing. Chapter Four is devoted to an analysis of present European practice relating to electrolysis mitigation. In Chapter Five the committee outlines certain researches which it deems necessary to have carried out in order to make it possible to reach a final solution of some of the fundamental questions pertaining to electrolysis mitigation.

The American Committee on Electrolysis which prepared this report is a joint committee having three representatives from each of the following organizations:

American Institute of Electrical Engineers.
American Electric Railway Association.
American Gas Association.
American Railway Engineering Association.
American Telephone and Telegraph Company.
American Water Works Association.

National Electric Light Association.
Natural Gas Association of America.
National Bureau of Standards.

Arrangements have been made for placing this report on sale by the American Institute of Electrical Engineers, 33 West 39th Street, New York, N. Y. The price is one dollar per copy.

November 25, 1921.

(This statement forwarded by ALFRED D. FLINN, a representative of American Water Works Association.)

CEMENT JOINTS FOR CAST-IRON WATER MAINS.

D. D. CLARKE*

(*By letter.*)

In the JOURNAL for March, 1922, under the heading "Pipe Joint Compounds," there appears a discussion which took place September 14, 1921 upon the relative merits of the compounds called leadite, — hydro-tite etc., participated in by a number of water works superintendents and engineers.

Without exception the speakers confined their remarks to their experience in the use of leadite or hydro-tite as a substitute for the poured lead joint for cast-iron pipe, long in customary use.

In no case, however, was mention made of the use of cement as a substitute for lead in its various forms or combinations, and it therefore occurs to the writer that a statement of the experience of the Portland, Oregon Water Department in the caulking of water-pipe joints with cement might make an interesting addition to the discussion.

Prior to the year 1915, poured lead joints were the only kind in general use for cast-iron water mains in this city. Lead wool had been used to a limited extent for under water work, and leadite had been experimented with in a small way; but the poured lead joint was the main dependence for pipe-joint work. In December of that year, 1915, there came to the notice of the writer, then engineer of the Water Bureau, articles in the *Engineering News* — (November 25 and December 30, 1915) calling attention to the experience of Wm. Mulholland, Chief Engineer of the Bureau of Water Works of Los Angeles, Calif., in the use of cement for cast-iron pipe joints in that city. Mr. Mulholland in his letter called attention to the issue of the *News* for December 8, 1904, which contained a letter from the late James D. Schuyler, Consulting Engineer of Los Angeles upon the same subject.

An examination of these papers, and the favorable results secured at Los Angeles, caused the writer to recommend the adoption of similar materials and methods in this city. First, the laying of an experimental line of 1 000 ft. of 8-in. pipe, which proved to be so successful that other lines speedily followed until at the present time, as I am informed by Chief Engineer F. W. Randlett of the Water Bureau, practically no other caulking material than cement is used, except in special cases where the main must be put into use before the expiration of the 48-hour period necessary for the proper setting of the cement joint.

* Consulting Water Supply Engineer, Portland, Ore.

The method of preparing the cement and filling the joint adopted here is practically the same as that used in Los Angeles, viz., First quality medium setting cement is used, mixed so dry that the impress of the hand will be left upon a small ball which will crumble when let fall from the height of twelve inches. The pipe should be laid upon a firm foundation; the spacing of the spigot in the bell may be effected by placing a small bit of lead under it. A small bit of yarn should be used, just sufficient to keep the cement from entering the pipe. After filling the bell with cement it is thoroughly compacted with a yarning iron, by hand. This will have to be repeated two or three times before the face of the joint can be properly smoothed and rounded.

To the present time there have been laid in this city approximately 27.8 miles of 4-in., 6-in., 8-in., 10-in., 12-in., and 16-in. pipe with cement joints. In addition to the foregoing, approximately 4 000 ft. of 24-in. and 30-in. pipe has been taken up and relaid with cement joints during the progress of " grade crossing " elimination work.

When the first line of 8-in. pipe was laid in 1916, minute leaks occurred which were entirely taken up in a few weeks time. In relaying the 30-in. pipe mentioned above it was placed in a concrete lined tunnel which afforded an opportunity of observing the leakage. When the pressure was turned on the 500 or more feet of 30-in. pipe in the tunnel section, the leakage was very considerable. After draining the water from the tunnel two or three times the leakage was noticed to be decreasing and at the end of six months had stopped entirely and all the joints have since remained tight.

At a later date it became necessary to raise 100 ft. of 16-in. pipe which had been laid with cement joints. This pipe was raised approximately 4 ft. under full working pressure of about 70 lb. without any leaks resulting.

Prior to the general use of cement as a jointing material, as indicated above, the Department instituted a series of tests to determine the degree of flexibility in the joints of cast-iron pipe when laid with joints of neat cement, leadite or pig lead. These tests were described by Mr. Randlett in a contribution to the discussion of a paper upon " Cement Joints for Cast-Iron Water Mains ", by Clark H. Shaw, Associate Member American Society of Civil Engineers, printed in *Transactions American Society of Civil Engineers*, Vol. 83, page 277. Mr. Randlett concludes from these tests, " that for all ordinary mains cement joints are superior to either lead or leadite," and his later experience has confirmed this opinion.

PROCEEDINGS.

February Meeting.

Boston City Club,

Boston, February 14, 1922.

The President, Mr. Frank A. Barbour, in the chair.

Karl R. Kennison, civil and hydraulic engineer, Boston, F. W. Scheidenhelm, hydraulic engineer, New York City, and Egbert D. Case, hydraulic engineer, New York City, were duly elected members of the Association.

The President. I recognize that this large audience has come out for a definite purpose, to hear the speaker of the afternoon, Mr. Goodnough. We have, however, a matter of some importance which it is necessary to bring to your attention. With the notice of this meeting the prospectus of the proposed Affiliation of Technical Societies was sent out to you. This proposed Affiliation is the result of a long series of informal meetings by representatives of different societies. It has reached the point now where the local sections of the American Institute of Electrical Engineers, the American Society of Mechanical Engineers, the American Society of Civil Engineers, the American Institute of Mining and Metallurgical Engineers, the American Society of Heating and Ventilating Engineers, and the American Association of Engineers, have voted in favor of this Affiliation. The matter comes up to the Boston Society of Engineers to-morrow night.

It has been contemplated from the beginning that the New England Water Works Association would become a member of this Affiliation. Some weeks ago your Executive Committee voted in favor of the principle. That did not commit the Society; it only gave us grounds for going forward with the movement.

The scheme is that an affiliation of societies shall be formed — not of individual members, but a grouping of societies; that this Affiliation will take over the present headquarters of the Boston Society of Engineers; that the Affiliation will be governed by councillors, two elected from each Society. If the New England Water Works Association joins there will be two councillors elected from this body who will sit on this council which has the control of the Affiliation. It is proposed that they shall take over the premises of the Boston Society, that they shall install a permanent secretary, that that secretary shall have secretarial assistants, one of whom

will probably be the present assistant secretary of the New England Water Works Association. This movement has nothing to do whatever with the identity of this Association. We go forward with our own work just as we are doing to-day; it is merely a grouping of societies for headquarters purposes.

This movement has been the result of some twenty years of dreaming. When the Engineers' Club was started it was hoped that it might be founded by a group of technical societies. We have sometimes thought we would have a building of our own or we would take the upper floor of some building under construction. This movement is based on taking what we have got — the headquarters of the Boston Society, and starting with that, with the hope that it will lead to something bigger in the very near future. There is reason to expect that the membership will run up to three thousand at the very beginning and there is a possibility of five thousand sooner or later.

At the meeting of the Executive Committee this morning the following vote was passed:

"VOTED:—That the Executive Committee recommend that The New England Water Works Association approve the purpose and general provisions of the Constitution of the Affiliation of Technical Societies of Boston submitted with the notice of the meeting of February 14, 1922, and that the Executive Committee be directed to appoint a suitable committee to represent the Association empowered to consummate the formation of said Affiliation, to prepare the constitution and by-laws, and to negotiate the necessary working agreement to govern the relations, rights and obligations of the Affiliation and The New England Water Works Association."

With this brief introduction, gentlemen, the subject is open for discussion.

MR. LEONARD METCALF. Mr. President, I have a resolution that I would like to offer at this time, which was prepared by Mr. Sherman and myself, which would put into effect the idea which Mr. Barbour has so clearly outlined to you. I will read the motion first, and then I would like to say just a word in support of it, if I may, without taking much of your time:

"WHEREAS, a committee of representatives of various technical societies, or sections of societies in greater Boston having an aggregate membership of over 3 500, have outlined a plan for an alliance under the name of The Affiliated Technical Societies of Boston, and

"WHEREAS, closer coöperation between technically trained men in the water works and engineering fields is desirable, to make more effective their influence in public matters, to broaden information, interest, and acquaintanceship; and

"WHEREAS, the past advantages obtained by coördination of effort, avoidance of duplication, maintenance of a common headquarters, etc., have been of much value to this Association; and

"WHEREAS, the proposed affiliation is in effect a further extension of the coöperation that has obtained for many years between this Association and the Boston Society of Civil Engineers; now, therefore,

"BE IT RESOLVED, that the New England Water Works Association approves the purpose and principle of the proposed affiliation and authorizes its Executive Committee to determine after careful investigation whether or not this Association shall join said affiliation, and if the decision shall be favorable, to appoint two representatives of this Association with power to act for this Association upon the Council or other representative body of the affiliation."

The war has served to bring home to engineers and to men such as are here to-day the country over—the water works men, the electric light men, the gas men and men in public utilities generally, technically trained men in general — that they might exercise a much larger influence for the public good if they were more closely tied together. We have felt that need in this city ourselves within the last year or two in certain measures that have come before the Legislature that seemed unwise legislation to water works men. It would have been helpful at that time if we could on short notice have called together technically trained men who would see the point at issue quickly and could have helped to formulate public opinion. This measure would help in just that sort of contingency. The plan has been tried out in a number of cities in this country — in Philadelphia, in Chicago, where during the war it was of tremendous advantage to the government; in Los Angeles and in many other cities it has worked well. In some cases it has been developed in a way to make possible certain club features, making it possible to have dinners in advance of the meeting. In other cases it has been simply a tying together of the various organizitions. There is the further fact, faced not only by associations of this sort but by small clubs, the country over, that expenses have increased so enormously that they have become very burdensome, and it looks almost as if many of our small societies and clubs were doomed. The only method of meeting the difficulty seems to be in some form of coöperation or consolidation. Now this organization has been set up on a basis of coöperation rather than consolidation, with the belief that while these different groups, such as this one, will prefer to continue to get together as a group, they may yet enjoy the advantage of combination and may occasionally like to get together with the other groups with a view to broadening acquaintanceship. The Boston Society of Civil Engineers faces this year a deficit of over $2 000. Its expenses to-day and next year will be greater, not only than its income under present dues, but than its income plus the income on its permanent fund; therefore it means a curtailment of activities involving financial support in order to meet the situation unless some such plan can be adopted.

This organization has felt the financial burdens. Therefore it seems the sensible thing to do — it has seemed so to many men the country over— to get together in such a way as this, so that the cost of maintaining the

necessary facilities that we all want will be reduced to a minimum, so that our power for good may increase without loss in identity of the organization or indeed of its independence. The effect upon the dues, I think, will not be material. Whether it will involve a little increase at first or not, I am not sure. I think it may involve a slight increase, but it will be small. It may well be possible to carry it without any increase. Within a few years I have no question that it will involve either a decrease or a very distinct improvement in the facilities open to members. I am confident that looking forward for a longer period of years, we shall find it possible with a larger group of four or five or six thousand members to have joint facilities such as are enjoyed in this club, — I won't say on so large a scale, but I mean, where men of our interest can get together and do their work satisfactorily and cheaply. Therefore it seems to me that it is highly desirable that this association should join with others in making possible the saving of expense to all of the organizations and in giving greater influence to the work which engineers may undertake. I see no serious disadvantages; I see very distinct possibilities in the movement, and therefore I hope it will prevail. I thank you for your attention.

Mr. David A. Heffernan. There is one thing which as a member of the Executive Committee and a superintendent I wish Mr. Metcalf would make a little clearer. This proposition will probably be misjudged on the part of some of the superintendents, who may feel that it involves losing the identity of the New England Water Works Association. This Association was formed years ago by superintendents. Now the superintendents here to-day might possibly misconstrue this matter, and if Mr. Metcalf would go into it from the superintendents' point of view to impress them that there will be no material change, I think they will go away better satisfied.

Mr. Metcalf. Mr. President, I am very glad to say a word along that line. As I see the movement, the intention of the movement and what I believe will result, it makes absolutely no change in this organization in your methods of doing business except as to detail, or in the way in which you will run this Society. We should have, as we have to-day, headquarters. We should have at those headquarters probably a managing secretary who will take care of the work of the Affiliation. That secretary will send out the notices upon request of the secretary of any one of these societies, so that the clerical force of the Affiliation may do certain detailed work. The library facilities will be maintained in common as they are to-day. They will be bettered by the fact that other organizations than our own will add their libraries to our library. An employment bureau will be run for the Affiliation for the benefit of all concerned — not this group or the Mechanicals or the Civils, but of all men. That is the cheapest way to do it. The elections of this Society and the procedure in regard to all business matters will be just as independent undert he future conditions as to-day. It would merely mean that we would have a central council to which we

would make appeal when questions of importance to water works men were to come up before the Legislature or elsewhere and the assistance of the Affiliation as a whole through its Council would be invoked at those times. On matters touching the public good as to which we could advise with advantage to the public, that advice would be given again through the Council through our representatives on the Council, who would take part in its deliberations and be the direct agency by which that work would be done. So that as I see it you sacrifice nothing in your independence; the Society, I should hope and of course I believe, will continue to be run by water works men, by superintendents, not by the engineers. No one organization will run the Affiliation; no group of men will run the Affiliation. The central organization does the work simply for the public good and the essential business that we all want to get rid of. The individual work of the individual society will still be run by its own officers. The individual societies will still have their presidents, their secretaries, whatever staff they wish to maintain independent of the Affiliation. But it is only in those matters as to which economy can be effected by joint use, by joint publications and so on, that we expect to benefit.

Now a word in regard to publication. At the present time, as far as the understanding has gone, it has been that all of these societies would save expense in publication of notices by having the notices go out at stated periods. That notice might be as it is with certain groups of societies to-day, a long list on which the meetings of A Society will be held, B Society, C Society, the different groups. The mailing would be done through the central office. In that way you would save a substantial amount of money in the clerical work of getting those notices out and in the cost of printing. Personally I believe that finally the Affiliation may well publish a journal to embody the important papers of the various organizations. That matter is wholly in the air; it has not been broached in the discussions of the men who have been particularly interested in the possibilities of this movement, so that that question will be decided later on by the Council with the approval of the societies affected. If this organization still wished to publish its own independent journal it would go on doing so. The Affiliation cannot of course say that it shall not do so; it cannot force it to support the other measures; but I believe it would be advantageous to the members of this Association if it were possible in the future to have the publications in one volume so that you would have the advantage of the interesting papers which are published by the Mechanicals, the Electricals, by the men of other groups as well as your own. But that is wholly in the air.

I do believe sincerely that this Affiliation will broaden the opportunities for men who are members of this organization. There will be under the plan as contemplated no overlapping dues. If a man is a member of three or four or five different organizations, as a number of the men in this hall are, the dues will be paid but once to the Affiliation. That is

one of the things which must and will be adjusted undoubtedly. Have I answered all your questions?

MR. HEFFERNAN. Yes.

THE PRESIDENT. Any other questions? Mr. Metcalf has made a motion that the New England Water Works Association approves the purpose and principle of the proposed Affiliation and authorizes its Executive Committee to determine, after careful investigation, whether or not this Association shall join said Affiliation, and if the decision shall be favorable, to appoint two representatives of this Association with power to act for this Association upon the Council or other representative body of the Affiliation. Is the motion seconded?

[The motion was seconded.]

MR. HENRY V. MACKSEY. In the circular sent out with regard to the Affiliation, there was a statement that the assessment on the various associations entering would not be more than $3 per year per member. Three dollars per year per member is not a large amount of money and we know that we do get some benefit from our present connection with the Boston Society of Civil Engineers and that we have had that benefit for years. We have not paid a great price for it and we ought to be willing to help them if their financial load is becoming too heavy to bear. It seems to me that we should consider whether, if we are called upon to pay $3 per year to the Affiliation, we would have enough remaining to carry on our own work and our own activities without materially increasing our dues. Many of us are paying dues to a number of societies and the total is a considerable sum. Would it not be well for us to consider the financial side more closely before our committee binds us by this agreement? We can very easily go in and while it may be easy to drop out again it could not be done gracefully. If we go in we must stick and carry through. What are we to gain at present other than that we will be in touch with other societies when we desire to take part in a public movement and that we will have a little more privilege in the apartments that we now occupy? The financial side should be presented more definitely, because, as Mr. Metcalf has said, it will not reduce our running expenses; in fact, will increase them. We cannot increase our running expenses without increasing our dues. There are many of us who believe that our own JOURNAL dealing only with water works matter is fully as useful if not more useful than one in which the best of our papers are incorporated with papers that are interesting to mechanical engineers, electrical engineers, gas engineers and others with whom we have no close business or professional connection and whose papers would be of no interest and perhaps go over the heads of many of our members.

THE PRESIDENT. I am glad Mr. Macksey has raised this question, because I think it is one that ought to be considered by the members before they vote on this proposition. While a definite statement cannot now be presented as to the cost to this Association of entering the Affilia-

tion, I can perhaps make an approximate statement which will leave the members content to give the Executive Committee power to act in this matter.

The assessment payable to the Affiliated Technical Societies will cover the cost of rent, of clerical services at headquarters, of printing and mailing notices, and of such other items which now altogether cost — under our present arrangement — somewhat under $3.00 per member. The prospectus of the proposed Affiliation states that the assessment shall not exceed $3.00 per member and — assuming this to be the figure finally adopted and that for this assessment we shall be housed and furnished services by the Affiliation, which now cost us but little less than $3.00 per member, it follows that the final cost to us will be about the same as at present, and it is, therefore, from present information not anticipated that any increase in dues will be necessary.

I assume that the Executive Committee — if authorized to act for the Association in this question — will carefully analyze the expense involved before deciding to enter the Affiliation, and knowing, of course, that the dues cannot be increased without vote of the Association and an amendment of the Constitution, will make their arrangements accordingly.

MR. PATRICK GEAR. Mr. President, if there is any superintendent here listening to this argument, I don't want him to go out of the hall by and by and say, "Well, it is too bad that we affiliate and become a small toad in a big puddle instead of being a big toad in a small puddle, as we are now." I am in favor of the Affiliation, but I don't want any superintendent to come around to me by and by and say, "Well, why did you allow that to go through in the Executive Committee?" I am in favor of it; I think it is a good thing. If we are affiliated with those men it will be a big help to us. We can make lots of acquaintances. I can go home and say, "I met a lot of big fellows in Boston; I was talking to them." [Laughter] If anybody has any fault to find, now is the time to find it.

MR. METCALF. May I say just one word? I am in sympathy with Mr. Macksey's viewpoint in regard to facing the question of finance. It is a perfectly proper question. The approximate rough analysis which I made of the expenses indicated that probably the increase in dues at the present time would be likely to be less than fifty cents, or somewhere about that figure. And as I said before, ultimately, and perhaps immediately, there would be a decrease. It was for that reason that I stated that it did not seem to me that it was likely to make any material difference to anybody in this organization in a financial way. So far as the publication is concerned, that, as I stated before, is a matter for the future. It is not involved in the present discussion. We have that and will still have that in our own hands.

THE PRESIDENT. Those in favor of this motion will please say Aye. [General response.] Opposed, No. [No response.] The motion is unanimously carried. [*Adjourned.*]

SAMUEL EVERETT TINKHAM.

SAMUEL EVERETT TINKHAM, who died on April 21, 1921, was born in Taunton, Massachusetts, on March 31, 1852. After attending the public schools and receiving additional instruction by a private tutor, he entered the newly established Massachusetts Institute of Technology, from which he was graduated in 1873 with the degree of Bachelor of Science in Civil Engineering. This was the sixth class to be graduated from this institution and he was, therefore, one of its earliest graduates.

After graduation, he served for a year as assistant in the Corps of Engineers of the United States Army, being employed on harbor improvement work in Edgartown, Massachusetts. In October 1874, he entered the engineering service of the City of Boston, with which he was continuously connected up to the time of his death except from 1882 to 1884 when he served as assistant engineer on the New York and New England Railroad in charge of the design and construction of bridges for the double tracking of that road. His services for the city prior to 1882 consisted chiefly of bridge engineering, although his duties also included work on the Boston Main Drainage System particularly in connection with the design and construction of the Calf Pasture Pumping Station of that system.

Soon after his return to the employ of the city in 1884, he received the title of Assistant Engineer and Principal Draftsman of the Engineering Department and until the late 90's his work was largely that of office supervision of the preparation of plans for highway bridges, a considerable number of such bridges being designed and constructed during this period under the direction of the Boston Engineering Department. As the engineering activities of the city increased, they became in time so extensive as to require him to devote practically all of his attention to supervision of construction, leaving the preparation of designs to others, and during the last quarter century of his service, he supervised the construction of many engineering projects of large magnitude, including not only bridges but grade crossing eliminations, sea walls and difficult foundations.

In the reorganization of the city departments which took place in 1911 and resulted in the establishment of the present Public Works Department, Mr. Tinkham was made Construction Engineer of the Bridge and Ferry Division, a position he continued to hold until his death. He also served as Acting Division Engineer in 1914 and 1915.

In addition to his engineering work for the city, Mr. Tinkham served as consultant on many bridges built in various parts of New England, on buildings and on foundation problems as well as upon certain phases of construction of the Metropolitan Waterworks System.

While his active engineering work brought him into close contact with City, State and Public Service engineers in the Boston Metropolitan district,

he was better known to the engineering profession at large, particularly in New England, as the genial, efficient and alert secretary of the Boston Society of Civil Engineers, a position which he filled with marked ability for 27 years preceding his death. During this long period, the interests of the Society were always prominent in his mind. New presidents took office knowing that in Mr. Tinkham they would find not only a thorough knowledge of the affairs of the Society and of the problems that confronted it, but that they would also receive his hearty and effectual coöperation in any measure that had to do with its welfare. Members at large knew that they would receive from him a cordial greeting at Society meetings and sincere and effective assistance in making use of the Society organization. His reelection year by year by general vote of the Society was a foregone conclusion.

In addition to his services for the Boston Society of Civil Engineers, he was for many years a member of the New England Water Works Association and was also active in the affairs of the American Society of Civil Engineers, having twice been a member and once chairman of its Nominating Committee and having served also as a member of other committees.

Amongst other of his numerous activities may be mentioned his connection with the Civil Service Commission of Massachusetts. In 1897, the provisions of the Massachusetts Civil Service law were extended to include engineers in municipal employ and in 1902 to include also engineers in the employ of the Commonwealth of Massachusetts. Mr. Tinkham was appointed, in 1897, as one of the members of the first Board of Examiners for civil engineers in the Classified Service, which position he held for more than fifteen years. During this time his influence was exerted in placing the examinations for engineers upon a practicable working basis to the end that a man's fitness for appointment to the various engineering positions in the city or state should not be based entirely upon his ability to pass written examinations but also upon experience and demonstrated ability.

This paper would not be complete without mentioning Mr. Tinkham's Masonic activities. As evidence of his faithful service and of the esteem in which he was held by his associates in the Masonic organizations to which he belonged, it is only necessary to cite his services as Worshipful Master of Washington Lodge in Roxbury, as Eminent Commander of Joseph Warren Commandery of the Knights Templars and as President of the Association which controls the Masonic Temple in Roxbury, Massachusetts.

All who knew Mr. Tinkham have a feeling of great personal loss and a sudden realization of how much his unselfish, honest, untiring interest in the various activities, whose success was so close to his heart, is going to be missed.

FREDERIC H. FAY.
F. A. MCINNES.
Committee

HERBERT L. HAPGOOD.

HERBERT L. HAPGOOD was born in Athol, Massachusetts, February 5. 1850. He was the son of Lyman W. and Eliza Hapgood. He was killed by an automobile when crossing the street near his home on the evening of October 8, 1921.

Mr. Hapgood was educated in the local schools and the New Salem Academy, which at that time had a high rating. After graduating from the academy he apprenticed himself in the Baxter D. Whitney shops of Winchendon, Massachusetts. Here the young man's mechanical inventive ability was developed.

Upon his return home in 1874 he entered his father's business, The Diamond Match Company, and carried it on until 1892. He perfected many patents valuable in the production of matches, a sandpapering machine being the most notable.

Mr. Hapgood came of a long line of patriots, municipal leaders all. After retiring from active business he entered enthusiastically into the executive business of the Town, holding the principal office for fourteen consecutive years, together with the management of various other departments, instituting some and supervising the construction of others, the sewage system, for instance. In 1909 Mr. Hapgood was made Superintendent of the Water Department and continued to be chairman of the board of commissioners, which position he had held for several years. He was particularly adapted to this work and it was agreeable to him. He developed the plant to its present efficient system and was formulating extensive improvements at the time of his death. The sand filter which he constructed, has filtered itself into exemplary fame among Engineers.

Mr. Hapgood was by position, disposition and knowledge a veritable Town Father; naturally a student, he weighed all questions imposed upon him from every angle, beginning with the legal and never forgetting the human element. Mr. Hapgood collected and prepared much historical data that is invaluable to the Town and the District — his works are his monument, they will endure without end.

Mr. Hapgood married Mary Josephine Proctor, in 1875; he is survived by his wife and two sons, Lyman P. Hapgood and Frederic H. Hapgood both Civil Engineers, and one daughter, Edith E. Hapgood.

ALFRED EARL MARTIN.

Born September 23, 1852, at Brooklyn, Conn.
Died February 21, 1922, at Springfield, Mass.

In the death of Alfred E. Martin the New England Water Works Association loses a member of sterling worth long active in the work of the Association. He was elected a member of the Association April 21, 1885, less than three years after its organization, and has rendered valuable service on committees from time to time, being honored by election as its president in 1908.

His early education was received in the public schools of his native town and in Woodstock Academy, living in Connecticut until he was twenty-one years of age, and teaching in some of its district schools.

Health prevented the realizing of his ambition for an advanced scientific training, but he continued along technical lines, working as a civil engineer with J. Herbert Shedd, chief engineer of the Providence Water Works and Sewer department, and Howard R. Carson from 1874 to 1877.

He was assistant engineer in charge of the Brookline main sewer, and in construction of a large filter basin in Lonsdale, Rhode Island; was engaged in sewer construction for the City of Boston, and in other construction work.

For four years he was superintendent of the construction work on "Dam No. 4" of the Boston Water Works at Ashland, under the immediate supervision of Mr. A. Fteley, C.E.

In 1885 he became superintendent of the Framingham Water Company, where for eighteen years he was a vital factor in the development of the Framingham system.

On March 1, 1093 he became superintendent of the Municipal Water Works of Springfield, Mass., where during the nineteen years of his service he saw the Springfield system rebuilt along modern lines and more than doubled in size and service.

During his thirty-seven years of service as a water works superintendent he was known as an excellent official and a capable, faithful and conscientious public servant. He was a faithful attendant at the Association meetings and his remarks and counsel were always considered sound and carried weight of practical experience. His frank personality attracted lasting friendships, and, as the Assistant Secretary has so aptly stated, "He will be missed greatly by the older members of the Association, and his genial manner, which was so genuine, will be a pleasant remembrance of him."

In 1879 he married Miss Eleanor M. Flagg of Providence, who died in Springfield, March 8, 1917. Besides a brother, Frank L. Martin of Brooklyn, Conn., he leaves a sister-in-law, Mrs. Clara A. Kilburn, who has lived

with him since Mrs. Martin's death, and four nieces; Miss Celia May Chase, formerly of Newton, Mass., Mrs. Andrew Sharp of Elliot, Conn., Mrs. Abbie Holbrook of Pomfret, Conn., and Mrs. William Farmer of Greenfield, Mass.

Mr. Martin was a past master of Alpha, A.F. and A.M. of Framingham, a member of Springfield Commandery Knights Templar, Massachusetts Consistory 32, and Melha Temple, A.A.O.N.M.S., and was also a past noble grand of the Odd Fellows in Ashland and a member of the Orpheus Club of Springfield and prominent in musical circles in both Framingham and Springfield.

He was one of the first presidents and a founder of the Public Service Associates of Springfield, Mass., a unique local "get-together" organization of officials connected with public work and public utilities in that city, which he helped to form some ten years ago.

ALFRED R. HATHAWAY,
ELBERT E. LOCHRIDGE,
Committee.

SPRINGFIELD, MASS.,
April 26, 1922.